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ABSTRACT

This book contains the proceedings of the annual RESNA (Association for the Advancement of Rehabilitation Technology) conference, which focused on technology and individuals with disabilities. Papers and presentations are grouped into the following nine major categories: (1) assistive technology and cognitive disabilities; (2) augmentative and alternative communication (AAC), which includes "Joint Attention and Young Children Relying on AAC: Research Implications for AAC Intervention" (Cynthia J. Cress); (3) computer access and use, which includes "Computer Access Considerations for Primary-School-Age Users" (Yuichi Tamano); (4) environmental adaptations, modification, and design; (5) functional control and assistance, which includes "Intramuscular Functional Electrical Simulation To Augment Walking in Children with Cerebral Palsy" (Rick Finson and others), "The Implementation of an Upper Extremity Neuroprosthesis in Growing Children with C5 Level Spinal Injury" (Brian T. Smith and Randal R. Betz), and "Totally Implanted FES for Upright Mobility in an Adolescent with Paraplegia" (Therese E. Johnston and others); (6) public policy and assistive technology education, which includes "Barriers to Effective Preservice and Inservice Distance Education in Assistive Technology" (Al Cavalier); (7) quantifying function and outcomes, which includes "Assistive Technology Outcomes in the Schools: Identifying a Valid Measure" (Michelle Kaye Silverman and others); (8) seating and mobility; and (9) service delivery and technology for special populations. The book includes papers from the fifth annual research symposium that address the medical, functional, and psychosocial consequences of aging with a disability and the impact on future needs for assistive technology. Presentations from the student design

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competition and the student scientific paper competition are also included. (Papers include references.) (CR)

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PROCEEDINGS OF THE RESNA '99 ANNUAL CONFERENCE

SPOTLIGHT ON TECHNOLOGY

JUNE 25-29, 1999
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SPOTLIGHT ON TECHNOLOGY
RESNA
'99
LONG BEACH, CA

June 25-29, 1999

Long Beach

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PROCEEDINGS
# of the
RESNA '99
Annual Conference

Spotlight on Technology

June 25-29, 1999

Long Beach Convention
& Entertainment Center

Long Beach, California

Stephen Sprigle, PhD PT
Editor

Kevin Caves, BS ATP
Barbara Ketcham, OTR
Conference Co-Chairs

RESNAPRESS

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RESNAPRESS

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Foreword

Can I afford to attend the RESNA conference? It's a common question in this age of shrinking reimbursement dollars and increased competition for them. Consider for a moment what the RESNA annual conference is all about. RESNA is the spotlight shining on all assistive technology issues. The RESNA Annual Conference is the ONE place where clinicians, suppliers, educators, researchers and consumers can step into the spotlight together, to share information and expertise, to teach and to learn, to combine their strengths in understanding and solving today's issues and in planning for tomorrow's rapid paced changes. The real question should be: "Can I afford NOT to attend the RESNA conference?"

Technology is changing our lives every day in every way. This week as we shine our spotlight on assistive technology, our intent is to highlight new equipment as well as new issues in the field of assistive technology. And what better place is there to engage in such an exchange than where the consumers, researchers, educators, clinicians and suppliers of assistive technology meet to share and learn. Only by staying informed and keeping communication open between the disciplines can the field of assistive technology survive as an entity that makes a difference in people's lives. Take this opportunity to get involved and let yourself and your thoughts be heard.

On behalf of the local organizing committee we welcome you to Long Beach, California, for the 1999 RESNA Annual conference. We hope you will find both the conference and the city of Long Beach, to be exciting and inspiring. Step into the spotlight to teach and learn about assistive technology and the issues, present and future!

Kevin M. Caves, BS ATP
Barbara Ketcham, OTR
Conference Co-Chairs

Alexandra Enders, OTR/L ATP
RESNA President

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Preface

Welcome the RESNA '99: Spotlight on Technology.

The members of RESNA and other attendees have again contributed a extensive variety of assistive technology information spread throughout the scientific program's platform and interactive poster presentations, computer demonstrations and concurrent sessions. The content includes everything from recent scientific research to practical designs to case studies.

You'll notice a few changes this year in the layout of the conference and proceedings resulting from an effort to simplify the conference for all attendees, but in particular, for those new to RESNA. All scientific content is grouped into 10 categories:

- Assistive technology and cognitive disabilities
- Augmentative and alternative communication
- Computer access and use
- Environmental adaptations, modification, and design
- Functional control and assistance
- Public policy and AT education
- Quantifying function and outcomes
- Seating and mobility
- Sensory impairments
- Service delivery and technology for special populations

Using a limited number of categories improves one's ability in selecting sessions of interest and greatly simplifies the process of designing the schedule with minimal conflicts. Of course, RESNA '99 is more than just scientific content, it is also about networking and planning. Many meetings are scheduled on a variety of issues and you should investigate those that pique your interest. Meetings represent the other significant change in conference organization. All meetings are held outside of the time periods reserved for the scientific program so attendees do not have to choose between a scientific session and a meeting.

RESNA '99 resulted from efforts by many people. Kevin Caves, the Conference Chair and the Chair of the Meetings Committee, led the planning and organizing at both the local and national levels. I'm fairly confident no one else will ever attempt that double. As always, the efforts of Susan Leone and Terry Reamer were indispensable. I cannot describe the many roles they undertake as the conference is planned and executed. Please thank them.

Enjoy.

Stephen Sprigle, PhD PT
Chair, Scientific Program

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Assistive Technology and Cognitive Disabilities

TRAINING ELDERLY PEOPLE TO STEP OVER OBSTACLES USING SELF-VISUALIZATION TECHNIQUES

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ABSTRACT

The long term goal of this work is to construct and test a system for elderly individuals at high risk for falling that 1) employs techniques to monitor and improve their stepping-over response trajectories and 2) trains them in more effective movement strategies. This method is expected to be safer than conventional training and more rapid and precise in the feedback it provides to the patient.

BACKGROUND

Currently, the standard method of training stepping-over responses involves exposing the subjects to the actual hazards, such as practicing stepping over different sized objects. Many activities can not be practiced because they: 1) involve too much of a risk, such as stepping-over a moving object, 2) may lead to an actual fall, such as stepping over barriers, or 3) are not possible to simulate, such as having a dog suddenly run in the gait path.

STATEMENT OF THE PROBLEM

Statistics on falls in the US document the serious consequences of the problem. Accidents (a majority of them are falls) are the fifth leading cause of death in those over 65. One percent of those that fall are admitted into a hospital with only half of these surviving after the incident. Approximately 90% of hip fractures in elderly people are caused by falls. Of those elderly people who were functionally independent before a hip fracture, 25% remain in long term care for more than a year afterwards, and another 35% must depend on mechanical aids or people for mobility. On a more positive note, the Public Health Service states that 2/3 of the deaths due to falls are preventable. Therefore, there is a great need to identify the causes of falling in the elderly and develop strategies for preventing falls.

RATIONALE

The ability to step over objects is an essential component of ambulation that enables a person to safely function in real world environments. This is especially important for persons with walking deficits secondary to musculoskeletal (amputations, post orthopaedic surgery) and neurological (stroke, head injury, spinal cord injury, multiple sclerosis, peripheral neuropathy, Parkinson's disease) problems. In addition, the frail elderly, a growing Veteran population, would benefit from this research.

A high percentage of elderly veterans are injured in falls, or require home or nursing home care to prevent the occurrence of falls. Veterans having either service-connected or post-service problems of walking and balance constitute the target population for application of results of this research. Providing better care to veterans who suffer from posture and gait disturbances leading to falls was cited as a priority need in a September 15, 1987 Clinical Affairs Letter from the office of Mark W. Wolcott, Assistant Chief Medical Director for Clinical Affairs.

Veterans who have difficulty walking for other reasons (e.g. spinal injury, amputation, sensory or post surgical gait deficits, cardiovascular insufficiency, Parkinsonism or other balance disorders) are particularly susceptible to falls and the possibility of injury by contact with objects in their environment. The number of veterans in these categories is large and increasing, given that over 40% of veterans are now over the age of 65. Presently, prevention of falls presents a disproportionate burden to the care-provider, since the fall-prone person lacks means for continuous reinforcement of safe ambulation. Transferring some of this responsibility for reinforcement back to the patient is a potential outcome of this project that is in accord with VA goals.

DESIGN

In the past several months a laboratory setup has been developed. Subjects will wear an overhead harness to prevent injury in the case of a fall during treadmill walking. A color video camera will be trained on the subjects' legs from the side. The subject wearing a head-mounted display will view this real time image. The computer will add virtual images of rectangular objects of varying heights and lengths at the subjects' feet. The subject will be instructed to step over the obstacles on each step. The computer will capture the images and detect any intersection of the user's feet with the virtual obstacles. A collision by the toe on the front edge of the object would indicate that the subject has not lifted the foot high enough, while a collision with the heel on the top of the object would indicate that the subject has not stepped far enough. Foot switches determine which foot is off the ground. The vibrotactile feedback would then be directed to the heel or toe of the foot that caused the collision.

PRELIMINARY RESULTS

Our pilot project work has led to the following conclusions:

> The most successful technique involves displaying a side-view of stepping on a treadmill while the viewer repeatedly negotiates computer-generated obstacles.

When stepping over obstacles during overground walking, young, healthy persons step over higher objects by increasing knee and hip flexion. This same strategy is employed when stepping over computer-generated obstacles displayed during treadmill walking.

When stepping over obstacles during overground walking, young, health persons step over longer objects by increasing stride length. This same strategy is employed when stepping over computer-generated obstacles displayed during treadmill walking.

In a small group of elderly subjects, the proposed training regimen showed a positive result: subjects were better able to negotiate an overground obstacle course after 3 training sessions. A randomized, controlled study must be conducted to separate out the nonspecific effects.

DISCUSSION

Future studies include studies on frail elderly individuals with a history of falls to determine if this intervention can result in reduced frequency of falls. In addition, we plan to further develop the system so that it can be used in a wide variety of clinical settings and clinical populations.

Further work in this project area could include employing simulation techniques with walking aids such as canes and crutches. Other potential areas of research include the study of improvements in fitness and gait through simulation of walking situations for ambulatory nursing home patients and teaching environmental factors and modifications to avoid falls. The system could provide an enjoyable and safe environment for general exercise, a safe setting for "wanderers", or a simulated practice session for wayfinding and familiarization of nursing home patients with their facility.

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ASSISTIVE DINING DEVICE PRODUCTION FEASIBILITY STUDY

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ABSTRACT

The purpose of this study is to develop a new design, develop clinical evaluation software, and to perform clinical testing of an Assistive Dining Device (ADD) that can help individuals with disabilities to eat independently. The ADD design is complete and two ADD units have been fabricated and are undergoing engineering test. Sixteen additional units for clinical evaluations will follow in late 1999. Clinical evaluation software has been developed which operates on a separate computer that can be connected to the ADD. Beginning in January 2000, these units will be used in extensive clinical evaluations to quantify the effectiveness of the device and to provide valuable user feedback about how well the ADD design fully addresses their needs. Evaluations will be conducted using the Tool for Evaluating Mealtime Experiences (TEME), an assessment instrument that has been developed to evaluate the quality of mealtime experiences for those using assistive feeding technology.

SIGNIFICANCE OF THE PROBLEM

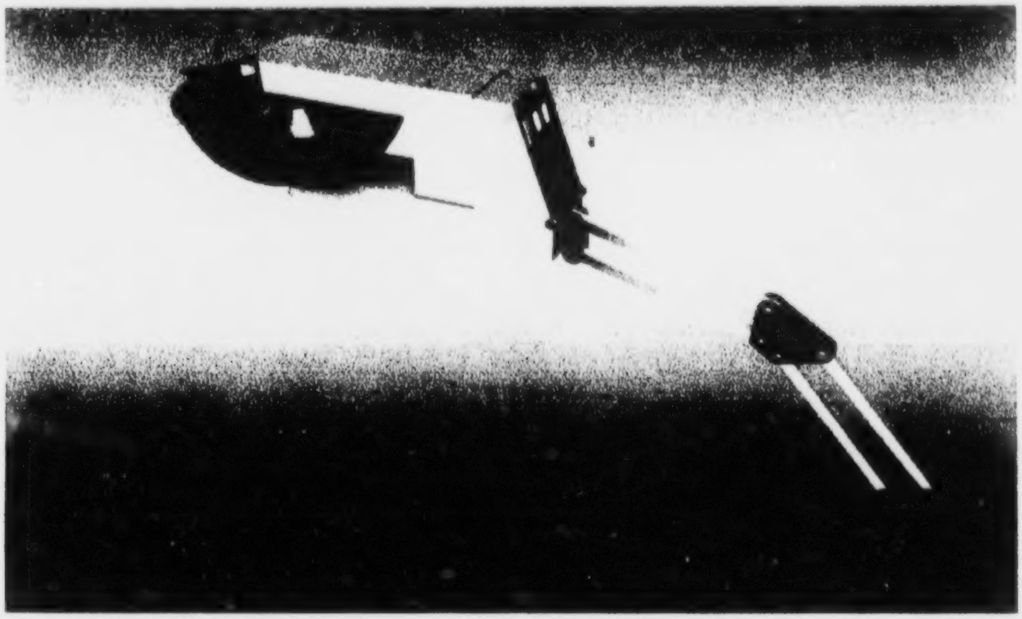
According to the U.S. Bureau of Census Population Report (1993), of the total civilian, non-institutionalized population, 487,000 adults need personal assistance with eating. About 60 percent of people with difficulty feeding themselves get help from others. However, one in five (21.4%) are unable to feed themselves even with aid (Disability Statistics Abstract)[1]. It is apparent from this information that at least 100,000 non-institutionalized adults in the U.S. are dependent upon a caregiver for their feeding and could potentially gain some independence by using appropriate assistive technology. Further evidence of similar statistics inside institutions was provided by a recent survey of 12 Occupational Therapy Departments from major U.S. rehabilitation hospitals who reported that out of 4,150 patients admitted to these institutions in 1993, 920 were completely dependent upon others for their eating needs (Mahoney & Phalangas, 1996).[2]

DESCRIPTION OF THE ASSISTIVE DINING DEVICE

The ADD, illustrated below, permits the user to select a food choice from one of the three sections of the bowl using one or two adaptive switches suited to his/her capabilities, or it can sequence automatically for users who cannot operate a switch. It serves a wide variety of commonly accepted table foods or specially prepared foods. The bowl rotates until the desired food is located under the spoon which then dips into the bowl, scoops up the food, removes excess food, and presents a rounded spoonful of food very near the lips of the user. The ADD requires a small amount of neck movement as the user must lean forward slightly and remove the food from the spoon. (A small amount of upper torso movement makes the device easier to access, but is not essential.)

THE ADD PRODUCTION FEASIBILITY STUDY

The ADD Mechanical Design. The first part of this study was to develop an improved ADD design. The design has been advanced well beyond that of the original ADD demonstrator, reported at the 14th annual RESNA Conference in 1991, which required separate electronics and a personal computer (PC) to operate. The current design contains an indigenous processor and control system and is entirely portable, operating on internal batteries. Although functionally the same as the demonstrator, the ADD physical and mechanical design has been significantly altered to provide a small, light-weight, reliable, readily cleanable product.



The Clinician's Workstation. The design also permits clinical evaluation of the user's ability to operate the device when interfaced with an external PC running software developed for this purpose; *The Clinician's Workstation*. The Workstation software operates under Windows 95/98 and provides complete control of the ADD from the PC. It also collects and stores detailed information about the ADD operation for sessions when the Workstation is attached to the ADD. Information gathered can be viewed on-screen and/or printed in a report. The data can be used to identify the optimum number and positioning of adaptive switches. During training, it can be utilized to analyze subject performance which will lead to the selection of the appropriate bowl and spoon movement patterns for each subject. It can also be used by a clinician to study their client's ongoing performance with the device and to determine if the control settings need to be altered. This data can be collected without the clinician being present and analyzed later. Using a portable computer, a clinician could easily support numerous clients.

Clinical Evaluation Design and Methods. The final objective of the study is to make quantitative measurements of the effectiveness of an assistive feeding device in the various environments where it might be required to function. A research plan that uses a within-individual design using multiple repeated measures has been developed. To balance the need for multiple subjects with cost and time constraints, a multiple-baseline design will be employed that will assess subjects' mealtime experiences with and without the ADD for six measurement periods. Subjects will be randomly assigned to one of three groups. Baseline data will be collected for all subjects. Group I will then be trained to use the ADD. When each user reaches competence in ADD operation, a second measurement will be taken with this group using the ADD. At the same time, groups II and III will receive a second baseline assessment. This process will continue until all three groups are trained and actively using the ADD. The final assessment will be a return to baseline for all subjects.

The Tool for Evaluating Mealtime Experiences. To develop the measurement methodology, an expert panel composed of specialists in research, assessment methodology, mental retardation, seating and positioning, eating disorders, and the development of training programs for improved eating and feeding, was charged with developing a draft instrument. A second panel was assembled to evaluate the draft instrument developed by the expert panel. The second panel consisted of users, their family members, caregivers, nursing and school staff. The ideas from this panel were later evaluated and integrated into the final instrument.

A researcher uses the check list portion of the TEME to collect information about the consumer's disposition throughout the meal. The meal is also videotaped. The social impact of assistive technology use at mealtimes is evaluated by analyzing the videotape and counting the number and types of communications with the consumer during the meal. Specific numbers of interactions that relate to ending the meal are also tracked during the meal. Information is gathered about the mealtime surroundings and atmosphere, including the number of diners and staff in the area, noise level, etc. The food and drink that is presented during the meal and the amount consumed, as well as information about all aspects of the quality of the food (e.g., temperature, appearance, smell) is recorded. After the meal, interviews with the user and caregiver are conducted to determine their opinion of, and satisfaction with, the overall meal.

Information gathered using the TEME can be divided into two categories: data which will be subjected to statistical analysis, and anecdotal data. All responses that will be analyzed are formatted to receive a negative or positive response or will be measured using a Likert-type scale with responses from zero (poor) to four (good). Data will be interpreted for within-individual efficacy by comparing changes between baseline and intervention. Group changes across time can be determined using repeated measures ANOVA.

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Swallow Frequency Device: A method of swallow detection

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Background

Humans produce between 0.5 – 1.5 liters of saliva per day (Blasco, 1996). Lear, Flanagan and Moorrees (1965) reported this saliva is swallowed during the nearly 500 swallow occurrences adults perform in a day. Children with developmental disabilities such as Cerebral Palsy do not swallow as often as those who are able-bodied. Sochaniwskyj, Koheil, Bablich, Milner, and Kenny (1986) determined that children with cerebral palsy and saliva overflow problems swallowed at 75% of the rate of normals. While this phenomenon has been studied in the laboratory, it has not been tested during the course of every day events in school, at home and in the community. A device, the Swallow Frequency Device (SFD) has been designed, fabricated and tested to perform this function. The SFD is comprised of a swallow sound transmitter, and a microprocessor. The SFD and its companion unit, The Chin Dry System™ act as an assessment tool, a training device and a research tool for persons with saliva overflow problems.

The SFD uses pattern recognition, which involves the storage of speech, swallow or other data vs. time in digital form in the computer or microprocessor. When a new data set enters the microprocessor, it is compared to the stored sample and, if they match, the microprocessor initiates a detection signal. Because no successive swallow or speech patterns are identical, the computer is normally trained by the subjects swallow patterns. The computer learns to recognize the variations in the individual subjects swallow patterns. The computer then learns to recognize and respond to a particular swallow sound despite small differences. Such significant strides have been made in pattern recognition hardware and software that it is now possible to recognize many patterns.

Research Question

The objective of this study is determine if existing pattern recognition technology can be adapted to swallow detection in subjects of all ages, and disabilities.

Method

The sound transmitter, a combination of a stethoscope and a microphone, has been shown to be effective when used with adhesives and placed at the lateral border of the cricothryoid cartilage. Placement of the stethophone is slightly lateral to midline of the throat. The stethoscope is comprised of a standard infant stethoscope with a simple piezo-electric microphone mounted at the end of the stethoscope head metal outlet tube (with the flexible section removed) using epoxy. The microphone voltage output signal is fed into the electronic counting component through three small wires. This combination had the major advantage that external non-subject sound signals were rejected from the desired signal. Further, acoustic low-pass filter properties of the stethophone reduce the effects of the subject coughing and speech. This device provides a simple and low cost yet effective approach to sound transmission.

Two separate SFD devices are in the process of development.

1. SFD4-MICROMINT
2. SFD4-OKI

The SFD4-MICROMINT was developed and will be described here. The template for the identification of swallows must be specific enough in form to eliminate non-swallow sound signals. Yet, the identification must be broad enough to identify somewhat different swallow data sets. The MICROMINT processor was configured to 'enroll' several different swallows from a subject and store several discrete swallow data sets. These data sets were then averaged to obtain a composite swallow pattern.

A thirteenth order polynomial fit was determined using a least squares curve fit. To reduce the sensitivity of this measurement to noise and other spurious signals, the mean of ten digitized samples was used to produce a new digitized compressed signal. This functions as a type of low pass filter without the phase distortions that would be encountered if an electronic filter were employed.

Results

The stethophone and the SFD4-MICROMINT were tested for four normal healthy adult subjects, three males and one female. All subjects gave informed consent. In each case, a swallow template was stored and compressed as described. Then, swallow signals, cough signals, speech signals, or simple noises were created by the subjects and the signal processed by the SFD4-MICROMINT. The results are given in Table 1.1. The results show 8 samples tested with 100% accuracy in swallow detection. The sample is small, with much more to be done, but the trend is very encouraging.

Table 1.1 Initial Testing of the SFD4-MICROMINT for Swallow Detection Accuracy

SUBJECT	SWALLOW	COUGH	SPEECH	NOISE
NO.1 (M)	ACCEPT	REJECT	REJECT	
NO.2 (M)	ACCEPT		REJECT	
NO.3 (F)	ACCEPT			REJECT
NO.4 (M)	ACCEPT			

Discussion

The SFD4-MICROMINT is a configuration using a low cost, industrially oriented controller on a 0.85 square inch Microchip Technology PIC16C84 RISC processor. It includes on chip RAM, EEPROM, and other features. This is a high performance, low cost, CMOS, fully static 8-bit microcontroller.

While the SFD4-MICROMINT shows potential for detecting the sounds of swallow, there is much more work to be done before its efficacy can be determined. The SFD 4 must be tested on 25-30 healthy adults and 15-20 children with cerebral palsy. Some of these children must have saliva overflow problems and some must not. In addition, the SFD4 must be evaluated using adults with acquired disabilities. This study population should be comprised of persons with ALS, Multiple Sclerosis, Spinal and Brain Injury, Down Syndrome and conditions resulting in the use of mechanical ventilation.

Efficacy must also compare the use of the SFD4 with another method of swallow detection. For this portion of the field testing, the SFD4 should simultaneous detect swallows while persons trained in videofluroscopy are monitoring swallows during a Modified Barium Swallow procedure. The real time view of the swallow using the MBS as the gold standard can be compared to the SFD4-MICROMINT. With trained personnel in attendance and indicating the swallow on video, this proves the efficacy of the SFD4-MICROMINT.

The SFD-4 will serve as an important component of the Chin Dry System™ because it increases its flexibility as an evaluation tool. It will be possible to measure not only the amount of saliva overflow but also the frequency of swallowing. It promotes the training capacity of the of the Chin Dry System™ by cueing the user as to when to swallow. Finally, it enhances the use of the Chin Dry System™ as a research tool. This will facilitate the development of knowledge of sialorrhea and saliva control. Perhaps clinicians can finally choose the best approach (surgery, medication, behavioral management or therapy) to this difficult problem.

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TECHNOLOGY FOR THE MANAGEMENT OF SALIVA OVERFLOW
THE CHIN DRY SYSTEM(TM)

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ABSTRACT

The Chin Dry System™ (CDS) is a technological and mechanical vacuuming system which vacuums unwanted saliva from the mouth, chin, or shirtfront of the user and stores the saliva for disposal. The portable and modularized CDS™ may be used for three purposes a) Functional Tool for Cleanliness and Hygiene: Saliva collectors are hand held, attached to the shirtfront, or adhered to the chin. Once saliva is detected, the CDS™ operates automatically or through user activation. b) Training Device: The CDS™, in partnership with the Swallow Frequency Device (see article by J. Allaire), alerts the user to swallow more frequently, to hold his/her head up, or to vacuum a saliva spill. c) Research Aid: Since the CDS collects saliva making it quantifiable, the researchers can begin to determine the effectiveness of interventions.

BACKGROUND

Drooling, (i.e., sialorrhea or saliva overflow) is the unintentional loss of saliva and other contents from the mouth (1). The topic of drooling typically generates unease, strained silences, embarrassment, or possibly jokes and amusing discussions. Drooling interferes with: 1) placement in the workforce for job-ready adults, 2) achievement of literacy skills for the school-aged population of children, 3) social relationships both intimate and merely familiar, 4) caregiver's burden of changing and cleaning clothing, and 5) technology interfaces (i.e. keyboard use). Poor saliva control occurs because of difficulty in the oral or voluntary phase of swallowing (2). It is both a clinical sign and symptom that is often a consequence of medical and/or neurological disorders (3). Additionally, clinicians who attempt interventions to prevent drooling cannot successfully: a) measure the amount of saliva produced by a person (measurement allows clinicians to determine the severity of the problem and to match the severity to a state of the art intervention); b) give the person who drools some effective control over the drooling problem, and, c) provide a hygienic means for removing drool and thereby eliminating odor.

In 1996, the National Institutes of Health, of the National Institute of Child Health and Human Development, funded this research project to develop a technology system that would address the condition of sialorrhea, i.e., unwanted saliva overflow. Researchers are in their third and final year of research to develop the Chin Dry System™ product to address the problem of drooling.

STATEMENT OF THE PROBLEM

The research question for this study is: Can a technology system be designed to adequately address the multiple problems presented by saliva overflow (i.e., drooling)? These problems are identified as: a) to keep the user clean and dry with am aesthetically and socially acceptable device, b) to develop a system which allows researchers and clinicians to evaluate the effectiveness of their medical and clinical interventions, and, c) to serve as a stand-alone training system to help the user change behaviors which contribute to the problem of drooling.

The Chin Dry System

RATIONALE
The Chin Dry System™ is a Hygienic Saliva Compensation System for use by individuals having uncontrolled drooling due to excessive saliva production or pronounced swallowing disorders to vacuum unwanted saliva from the mouth, chin, shirtfront of the user and stores saliva for disposal

DESIGN
The main components of the CDS™ are Saliva Collector Units, Saliva Collection Container, Pump, Solenoid, Battery, Swallow Frequency Device (optional), Head-Tilt Monitor, Data Collection and Evaluation Software, Configurable Input and Output Software for Training and Use, X-10 Environmental Controls and Battery Controlled Devices for Cueing and Training

The CDS™ has a portable carrying case that holds a vacuum pump and a self-contained power supply that powers the vacuum pump An electrical computer control circuit connects to the self-contained battery power supply and the pump The Three Collector Units are the saliva vacuuming components The Collectors attach to the connectors of the main operational unit by vacuum tubing and an electrical connector There are three Saliva Collectors are the Face Collector, the Shirtfront Collector, and the Hand-held Collector The Shirtfront Collector is used in combination with either the Face Collector or the Hand-held Collector as a back-up collector

The vacuum flow system consists of the following two tubing flow paths from two separate collectors, a flow vacuum route valve which directs the vacuum to the appropriate collector that has saliva, a vacuum pump, and a collection jar The vacuum pump is controlled in one of two ways 1) the user activates a switch or 2) a saliva detection sensor in the saliva collector initiates action The system, under programmed microprocessor control, is capable of sensing saliva in either of two collectors, switching the vacuum route valve to the appropriate flow path, and turning on the vacuum pump which suctions the saliva In order to maintain the integrity of the pump, air is routed through the collection bottle to pull the vacuum and prevent saliva from travelling through the pump Suction is maintained by pumping air out of the fluid collection bottle

The Chin Dry System™ microprocessor collects and stores data about all the interactions between the user and the technology Input is from collectors turning on and off, the duration of vacuum, the Head-tilt sensor, and the Swallow Frequency Device (see paper by J Allaire) The software can be configured to match inputs with outputs and to collect and store data Using an RS-232 cable link, software configurations can be uploaded to the Chin Dry System(TM) microprocessor from a clinician's PC to collect data and, conversely, collected data can be downloaded to the PC For training and cueing purposes, the Chin Dry System(TM) incorporates X-10 environmental control technology and speech output

DEVELOPMENT
Research Team The research team is comprised of the Principal Investigator, 2 mechanical engineers, two electrical engineers, a technology coordinator, two software engineers, an engineering prototype company, research assistant, and consultants from the Dept of Pediatric Developmental Disabilities at Texas Scottish Rite Hospital for Children (TSRHC) in Dallas

The Chin Dry System

Research Subjects Key participants of the research team are the 25 research subjects who have the condition of saliva overflow The role of the research subjects is to offer ongoing input and assistance on the design and function of the CDS as it evolves The research subjects were selected based on referrals from the patient population of TSHRC, plus referrals from the Muscular Dystrophy Association and United Cerebral of Greater Dallas From a pool of up to 35 potential research subjects, each subject was evaluated for severity of the drooling problem, willingness and ability to participate, and the ability to adequately communicate

EVALUATION

Over the course of approximately two years, researchers consulted on a regular basis with the up to 25 research subjects as to the design and functionality of the CDS™ The principal investigator would meet with the research subjects (and oftentimes their parent or guardian when appropriate) would use the equipment, and offer design suggestions, corrections and enhancements Researchers would make agreed-upon changes in the technology, and again interview the research subjects with the changed design, and the cycle would repeat Based on this use and evaluation of the CDS™, the current system is designed to be as functional and efficacious as possible Some components of the CDS™, such as the Hand Held Unit, have gone through approximately 15 generations of design in order to be appropriate for the users By September of 1999, six months of daily testing of the CDS™ will be conducted with up to 15 research subjects These subjects will use the CDS™ on a daily basis to finalize the refinement of the technology

DISCUSSION

This research has been a worthy effort to try and address one of the more stigmatizing problems encountered by people with disabilities drooling This is an important first step in a solution

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** The Chin Dry System$^{(TM)}$ is a product under development Innovative Human Services Inc is seeking a potential manufacturing partner For information on the Chin Dry System™, please contact the

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Augmentative and Alternative Communication

THE USE OF STORED TEXT FOR SOCIALLY EFFECTIVE CONVERSATION

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ABSTRACT

For people who are unable to speak but are literate, an AAC device based on self-stored text is a realistic option for social conversation. When pragmatic aspects of unaided conversation are successfully modelled in a text pre-storage system, the social effectiveness of users' social conversations can increase dramatically. It is argued that gains in conversational rate, management of turn-taking, and topic control that can be achieved with a predominantly pre-storage system more than offset any loss in the precision of responses to partners' conversational turns. Findings from studies that evaluate the content of aided conversations and investigate the effect of conversational rate on enjoyment and competence attributions are summarised in support of this argument.

BACKGROUND

People who are literate but unable to speak can use text-based AAC devices with synthetic speech output to communicate. Typically, however, the pause lengths before phrases are output are considerable. With users' conversational rates due to the long pause times rarely exceeding 2-15 words per minute, socially effective conversation is difficult to achieve. Users report that partners are unwilling to wait for long utterances to be produced, creating pressure to produce short, telegraphic phrases and conversation tends to reduce to partner questions formulated to elicit 'yes' and 'no' responses. Users rarely manage to take a full share in the control of topic content or in the management of turn-taking. Consequently they tend to attract negative attributions regarding their social competence, intelligence and how interesting they are.

One approach to this problem is to provide predictive support for the generation of phrases during a conversation, but advances in predictive power yield diminishing returns and conversations conducted in this way generally remain too slow to be socially effective. Pre-storage of text ready for retrieval in whole phrases during a subsequent conversation can speed up output considerably, provided there are only a few messages stored so that the required one can be located quickly. Pre-stored phrases may be regarded as suitable for passing simple 'needs and wants' messages or for highly routine interactions such as greetings and goodbyes or shopping in a store, but it is usually assumed that they are inadequate for conducting free-ranging social conversation. There are three basic objections. First, it is impossible to predict with accuracy what directions a conversation will take. Second, even when the direction a conversation takes has been anticipated, the prepared phrases will only approximate precise responses to what a partner says. Third, the more that is stored in an effort to be prepared for the different directions in which a conversation may go, the longer it will take to locate particular responses as they are required.

STATEMENT OF THE PROBLEM

The problem therefore is twofold. First, there is the issue of how to strike a balance between on-line text generation (i.e. during a conversation) and pre-storage facilities within an AAC device. As most AAC systems are based on the generation of content during a conversation, sometimes with provision for storage of a few phrases, it appears that most developers of AAC systems favor a balance that lies well toward facilities supporting on-line generation. I will argue that this is unfortunate. Second, if it is decided that substantial pre-storage facilities are desirable, a way must be found to help the user to prepare content that will include acceptable responses to most things that a partner may say and to organise their storage in a way that makes it as easy as possible to locate phrases as they are required. I will describe in outline the approach that has been taken to achieve these goals in an AAC system known as 'TALK'.

APPROACH

In contrast to transactional interactions, most casual conversation is motivated more by social and personal goals such as enjoyment of the interaction and creating a favorable impression than by a requirement for the accurate transmission of information. There is evidence that many phrases in natural conversation (particularly idiomatic phrases) are retrieved whole from memory and that many, particularly those concerned with personal narrative, are recycled in conversations with different partners (1). There is also evidence suggesting that people do not generally spend time generating very precise responses in social conversations, but focus on saying something more or less appropriate as quickly as possible.

Another pragmatic aspect of natural conversation is the way in which topic development typically progresses in small steps between different perspectives, for example, between *'talk about me'* and *'talk about you'*, between talk about the *'what'*, *'when'*, *'where'*, *'who'*, *'why'* and *'how'* of events or views, and between a focus on *'past'*, *'present'* or *'future'*. As an illustration, topic may shift from discussion of where I did my degree (*me/where/past*), to why I did it there (*me/why/past*), to where you did yours (*you/where/past*), to who supervised your thesis (*you/who/past*), to how you feel about the thesis now (*you/how/present*), to what research you're planning to move on to next (*you/what/future*), etc.

These pragmatic aspects of natural conversation were modelled in the development of TALK, a conversation aid based on the pre-storage of text (2). Specific features of TALK include the following. Menus of idiomatic-type comments provide acceptable responses to many different things that a partner might say (e.g. 'What a drag' in the *sympathy* category, 'That's a good question' in the *hedging* category and 'How about you?' in the *questions* category). There are quick-fire buttons always available on screen. When one of these is activated, a randomly selected exemplar of the response category on the button label is spoken (e.g. if the *'Good'* button is activated, any one of the following might be output: *'That's great'*, *'Oh good'*, *'Terrific'*, *'That sounds good'*, etc.). Substantive topic content phrases are organized within a *person/issue/tense* perspective framework that has the merit of remaining stable across all possible topics. This makes it relatively easy to find stored phrases and to share fully in the control of topic direction and the management of turn taking.

RESEARCH FINDINGS

The earliest TALK prototype had no facility for the on-line entry of text during a conversation. This was in order to test the limits of exclusively pre-stored content. Studies in which the user was a person without any speech impairment established that conversations on a specific topic, such as 'holidays' could be sustained using only pre-stored text, with output rates (including search times) of around 60-70 words per minute and with the TALK user taking a full share in the control of topic direction (2). These conversations were shown to have coherent speech act structures that were very similar to those found in unaided conversations on the same topic (3). It was also found that blind ratings of the social effectiveness of the contents of random segments of the conversations were higher for the aided conversations than for those between two speaking partners (4).

Single-case studies with non-speaking users with motor neurone disease (5) and cerebral palsy (6) established that similar conversational rates to those obtained with simulated use were possible, even when topic content was completely unrestricted. These studies also found a positive relationship between a user's conversational rate and both participants' rated enjoyment of the conversation. It was also striking in the second of these studies that, even though the user was achieving much faster conversational rates than are usual for AAC users, her partners judged that her conversational competence was more compromised by the difficulty she had in being fast enough than any difficulty in expressing what she wanted to say.

For recent studies, an on-line entry facility with word prediction was added to TALK. In one study it was found that when a user with cerebral palsy had the option of using on-line entry or pre-stored content, she only resorted to on-line entry for about 4% of her responses to unfamiliar partners and for about 7% of her responses to a familiar partner with whom she had regular conversations (1). In another extension of TALK, a *story-telling* mode was incorporated to complement the existing *turn-taking* mode. In the familiar-partner conversations referred to above, the user's conversational rate increased to about 80 words per minute as she made greater use of extended personal narrative.

IMPLICATIONS

It is now clear that, in principle, a basically pre-storage AAC system, with an on-line back-up facility, can support relatively effective social conversation for some non-speaking, literate users. It is strongly argued, however, that in order to achieve the potential of a text-pre-storage approach, it is necessary for researchers to consider the pragmatics of natural conversation; that is, what contributes to 'making it work' in terms of achieving users' social and personal goals. It needs to be recognized that there is more to effective conversation than being able to generate well-formed phrases that are accurately responsive to what a partner has just said.

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A LANGUAGE ACTIVITY MONITOR FOR AAC AND WRITING SYSTEMS: CLINICAL INTERVENTION, OUTCOMES MEASUREMENT, AND RESEARCH

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ABSTRACT

Clinical intervention, progress measurement, and research play important roles in leading to successful outcomes for people who rely on augmentative and alternative communication (AAC) and/or assistive writing (AW) systems. The Language Activity Monitor (LAM) was developed to allow actual language activity to be the basis for clinical decision-making, research and outcomes measurement. The LAM records characters transmitted on the serial port of the AAC or AW device and adds a time stamp to each character or character string. The recorded information can be uploaded periodically to a computer for analysis.

BACKGROUND

Improved spoken and written communication is the main goal for recommending an AAC or AW device. Monitoring outcomes for the expressive communication of an AAC or AW device user begins with a collaborative team approach (1). Current best practice emphasizes the need for systematic clinical data collection by teams to infer outcomes (2, 3). Systematic data collection should include objective measures on language and non-language parameters of device performance by consumers. Objective language measures document information collected from traditional language sampling and observational procedures. Language sampling provides information relative to the semantic and syntactic structures used in context as well as information on mean length of utterance (MLU) and developmental levels. Objective non-language measures involve identifying access method and rate. Systematic data collection of device performance can contribute to research on the identification of system features and intervention methods that produce the most desired results. Clinical intervention, periodic progress reporting and research all can be enhanced through monitoring the daily language activity of individuals using AAC and AW devices.

STATEMENT OF THE PROBLEM

Traditional methods of monitoring AAC and AW device use are based on clinical observation and video or audio recording with subsequent observation, timing and/or transcription (4, 5). The cost of this approach is high because of the human time investment. Also, the information is not immediately available for use. Consequently, professionals seldom perform language-sampling procedures to collect data on the actual daily environmental use of AAC and AW systems. Therefore, little research or empirical data exist on AAC and AW device performance by consumers to substantiate the clinical intervention process, report progress and evaluate outcomes.

RATIONALE

A solution to this situation is the automation of the language data collection and analysis processes. Efforts made in this area to date are all integral to specific communication or writing systems (6, 7, 8). Some commercially available AAC devices have included limited features that monitor use, but none have incorporated time information or provided the function for automated text editing. For example, the Liberator allows communication to be recorded in a notebook and the

DynaVox counts the number of times a given key has been selected. The LAM was developed to log actual language activity of AAC and AW consumers in clinical and/or natural environments. The logged data becomes the basis for clinical intervention, outcomes measurement, and research. As shown in Figure 1, the LAM connects to the serial output of an AAC or AW device. It records characters being transmitted and adds a time stamp to each character or character string. The recorded data can be uploaded periodically to a computer for editing and analyzing. A total system would consist additionally of an editor, language analysis program(s), and clinical intervention program(s).

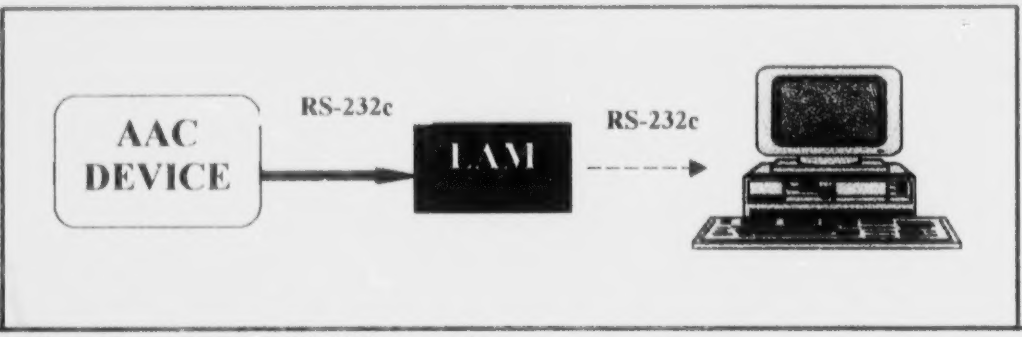

Figure 1: Illustration representing LAM connection

DESIGN

The design was a team effort, including contributions and surveyed responses from professionals and consumers with clinical speech-language pathology (SLP), research and technical expertise. Design features of the LAM that were identified initially included:

- Universal application across many devices
- RS-232c input and output
- Sufficient memory for meaningful data logging
- Real Time Clock for time stamp
- Battery power with a charge life of at least one week
- Simple Enable, Disable, Upload, and Erase controls
- Both pushbutton and serial input function commands
- Small size for attachment to AAC devices

DEVELOPMENT

The LAM has been developed around a ZWorld LP-3100 low power controller using the ZWorld Deluxe Dynamic C development tools. C programming provides for ease of development and maintenance and the potential transport to other hardware. The use of this hardware precluded the necessity of a hardware development project and the delays associated with that process. However, limitations may be encountered on the amount of available data memory and the consumers' need to set baud rates for compatibility. Additional development criteria have focused on simplicity of use such as ease of attaching and connecting the LAM to the AAC device, and ease of disabling the LAM.

EVALUATION

At the time of this writing, evaluation has not been completed. The evaluation plan includes beta testing and the comparison of the LAM automated data collection method with traditional language sampling methods from the perspectives of accuracy, effectiveness and cost. In addition, consumer feedback will be solicited during the Evaluation phase for modifications in the final product.

DISCUSSION

A component of the development process was the establishment of a protocol for reporting test-retest results and outcomes. Later phases of the project involve development of editing and analysis tools that use the output of the LAM. As LAM functions are analyzed, specific features may be designed into future AAC and AW devices. Therefore, a need for standardization of the protocol is critical for future application (9).

One important issue in the use of any recording device is privacy. For example, the LAM used with an AAC device can be disabled three ways to control for privacy. Individuals whose communication is being monitored should be clearly informed, and public use of recorded communication should remain anonymous.

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A Proposed Standard for AAC and Writing System Data Logging for Clinical Intervention, Outcomes Measurement, and Research

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Abstract

In the areas of augmentative and alternative communication (AAC) and assistive writing (AW), long term monitoring of use for the purposes of clinical intervention, outcomes measurement, and research is being pursued (1). Information being recorded includes language activity, text generation, non-language functions, date, and time of day. The logged information is then edited and analyzed. In order to assure compatibility between various recording, editing, and analysis features and tools, standardization of the reporting protocol is being proposed.

Background

Principles of evidence-based practice and outcomes management emphasize the need for standardized outcome measures to support clinical decision-making and evaluate intervention services. With the shift toward accountability, improving databases as well as integrating them across service delivery sectors and geographic borders would have a tremendous impact on outcomes measurement (2). Currently, a validated, easily accessible, uniform data collection system does not exist that allows us to critically analyze the outcomes related to assistive technology device performance or clinical intervention (3). Clinicians, researchers and consumers could benefit from systematic monitoring of AAC and AW system performance within the clinical setting and daily environments to measure outcomes.

Statement of the Problem

Empirical data from device users are needed to substantiate the effectiveness of AAC models, technology and intervention strategies (4, 5). However, the impracticality and high cost of traditional language-sampling and observation methods restricts the monitoring of device use, especially within natural contexts and activities of daily-living. At this time, automated tools are being developed for logging the language activity of AAC and AW devices (6, 7, 8). These tools may consist of monitor, editor, and analysis functions. As the acceptance of data logging grows, the compatibility of the various monitor, editor and analysis functions will be important.

Approach

The essential function of data logging is the recording of each event and the time that it occurs. A standardized monitoring protocol would facilitate the widespread application of actual user-performance data collection.

For a language event, the proposed protocol is:

hh:mm:ss "Any continuous text that is transmitted by the AAC device."

where (hh:mm:ss) represents the time of day in hours, minutes, and seconds using the 24 hour clock format. Characters following the (hh:mm:ss) and one space are the characters that were selected on the AAC or writing system in a continuous sequence with no time between characters greater than 0.2 seconds.

For a non-language event, the proposed protocol is:

hh:mm:ss "*[NON-LANGUAGE INFORMATION IN CONTINUOUS TEXT]*"

For example, consider the individual using an AAC device who is thirsty at a loud party. If he is using a language representation method that can access the series of individual core vocabulary words and phrases "I need ", "something ", "to drink " (spaces included) and then spells "immediately " using word prediction, starting at exactly 8:37 PM, then the representation for that series output would be:

```
20:37:00 "I need "
20:37:05 "*[VOLUME UP]*"
20:37:06 "*[VOLUME UP]*"
20:37:07 "*[VOLUME UP]*"
20:37:14 "something "
20:37:19 "to drink "
20:37:16 "i"
20:37:20 "m"
20:37:24 "m"
20:37:28 "ediately "
```

At the beginning of each day, a date notation is made:

[YY-MM-DD = 98-10-12]

Certain functional commands could be standardized. The system should provide the individual with method(s) for disabling and enabling the recording. It may be necessary to set the date and clock, such as at daylight savings time transitions or when changing time zones, or if the battery was allowed to fully discharge or needed replacement. Protocols for these functions are:

DISABLE	Disables the recording.
ENABLE	Enables the recording.
HH-MM-SS = XX-XX-XX	Sets the clock
YY-MM-DD = XX-XX-XX	Sets the date

Implications

The successful development and voluntary adoption of this proposed standard will facilitate the development and application of tools for monitoring AAC and AW system use. Standardize assessment tools will make it easier to accumulate and compare aggregate outcomes across various parameters (9). Standardization of the monitoring protocol will provide comparable, compatible and reliable quantitative data for a variety of clinical and research applications. This in turn will benefit people who rely on these systems through improved clinical intervention service, more consistent, periodic performance reporting ,and more precise and effective outcomes management.

Discussion

One important issue in the use of any recording device is privacy. People whose communication is being monitored should be clearly informed, and public use of recorded communication should be anonymous.

Contributions to this standard development effort are invited.

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Development of a Voluntary Standard Format for Augmentative Communication Device Logfiles

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ABSTRACT

The means for evaluating human-machine interaction in Augmentative and Alternative Communication (AAC) has not followed the technical advances in the field. We propose the development of a voluntary standard for AAC device logfiles. An an initial approach and set of logfile specifications are proposed.

STATEMENT OF THE PROBLEM

Over the last few years we have witnessed a rapidly increasing technical sophistication in augmentative communication devices. Such achievements include dynamic and animated displays, advanced prediction engines, hybrid selection algorithms, neurophysiological access methods, and many other technical achievements. In contrast, methods for measuring these systems have not progressed at the same pace. One reason for this discrepancy is due to the lack of computerized research tools permitting the real-time analysis of human behavior and computer processes.

To date, most studies of human-computer interaction in augmentative communication are conducted either with experimental systems, or by monitoring standard AAC devices using indirect methods (1,2). Experimental systems provide precise information regarding the human-computer events, but they may not resemble their real-world counterparts in important ways. Conversely, standard AAC devices are real enough, but don't provide the means for monitoring the events required to understand and model how humans relate to and interact with the technology.

Studies that cannot be easily performed with current technologies

Pointing out several studies that currently can't be performed can best convey the current state of augmentative device assessment. Note that such investigations could have considerable impact on bettering the communication lives of our consumers. Moreover, they index a field of research, which in our opinion, is important and grant-fundable.

Development of navigational skill using Dynavox's paging system. This type of study would focus on the acquisition of an augmentative communication system. A longitudinal research methodology would be called for utilizing repeated sampling of user-device interactions in experimental and naturalistic settings over a prolonged period of time. Logging of temporal, action and location events and the indexing of content at each page/level would be required.

Performance differences related to static versus dynamic prediction lists. Different selection algorithms and vocabulary organizations may impact on an individual's performance, especially with considerable practice. This is another longitudinal study involving the collection of precise timing data in various communication contexts. Information is needed, at an event level, focusing on the temporal characteristics of the prediction list display, letter and list selection and the subsequent display of the selected information.

Real-time performance differences in semantic compaction, word prediction and dynamic display paging systems. The evaluation of real-time performance differences across AAC platforms deserves significant attention from researchers in our field. Such studies could be performed in

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both the laboratory as well as the field. Here, we need to identify various system events, contextual information and accurate timing data. Further, this information needs to be sampled in a similar manner and formats - *across different manufacturers' AAC systems*.

Because of the relative size of our community and relative lack of research resources, cooperation is essential if we are to make significant advancements. The development of a voluntary standard for log files would allow the researcher, the clinician and the manufacturer to directly assess augmentative devices and user's interactions with devices. Based upon a standard logfile format, we could develop software that would enable manufacturer's to optimize the performance of their technologies, allow researchers to study how communication technologies are used, and enable clinicians to efficiently and validly assess their performance and adjust devices to suit their client's needs. In our own lab, the use of standardized logfile protocols have enabled us to automatically reduce, analyze and graph over 100,000 device-generated events in a matter of minutes.

APPROACH

Plan of Action

The standardization of a logfile protocol should involve a consensus building process involving the research, manufacturing, clinical and consumer communities. We propose that the American National Standards Institute (ANSI) be used to sponsor its development (3). The purpose of ANSI is to administer the U.S. voluntary standardization system, provide a national consensus process and to represent U.S. interests in international standardizing bodies. We have developed a website[1] to facilitate discussion about a logfile standard in order to help set a focused agenda for the ANSI Standards committee.

Content and Structure of the Logfile

It is premature to propose a standard protocol at this time; however, we would like to offer the beginnings of a workable model. There are several kinds of data that need to be included in a logfile: the current state of the system and context in which activity is taking place, the actions of the user with the device, the consequent actions taken by the device as a result of the user's input and derived measures.

State and contextual data would include information about the current system configuration (access method, dictionary employed), the current state of the user interface (e.g., page), and the message context preceding the users current action(s). Contextual data may include prediction word lists functional at the time of the selection as well as the sentence context in which a word is being spelled out. Timing information may also be considered contextual data. For example, the delay times of scanning systems may be updated periodically. Contextual data may appear as heading information or be included in the log file with each update.

User-interactions with the interface constitute another general category of behavior that needs to be recorded. Information to be logged would include the position and content of the display token being accessed. Each user-device interaction should be time-stamped. Due to the precision required to measure many user-device interactions it is recommended that timing information be recorded at a 100th of a second resolution. Temporal data should initially be calculated in terms of absolute time; other temporal measures can be derived from these data.

Device actions constitute a wide range of events generated by the AAC device in response to user input and/or other device or environmental sources (e.g., time of day). Data would include all navigational pointers, mode and content of information displayed, computer control commands, and timing information associated with the actuation of these events.

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[1] http://www.buffalo.edu/~cdsjeff/logfile.html

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Derived information would include a set of intermediate calculations that can be easily handled by the device without sacrificing performance. These may include latency and duration information, determination of user errors, whether interface information has been updated, etc.

How should the data files be set up? One basic consideration is to make logfiles accessible across Unix, Windows and Macintosh microcomputer platforms. Further, data should be able to be read in, parsed and analyzed using a variety of general-purpose analysis programs. We recommend that

Software rather than hardware approach

Two approaches may be taken to facilitate data collection. As advocated by Romich (4), a hardware "box" may be attached to an I/O port to intercept output directed to the data collection device. This approach has the potential of being used across a number of different devices and standardizes the downloading of logs to the data analysis system. However, one does incur the additional expense of the data collection device, it is currently limited to 256k memory and requires the developer to develop their system to output information in parallel to its operation. This solution may be problematic depending on the amount of data output. We also recommend a software solution where the manufacturer creates and stores logfiles in the device's memory. Files can be downloaded onto the analysis platform after being collected during a communication activity. This solution overcomes the cost and dependence on an external data collection system and may overcome memory limitations.

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A SEMANTICALLY-BASED SOFTWARE IS DEVELOPED FOR PEOPLE WITH ALS

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ABSTRACT

Amyotrophic Lateral Sclerosis (ALS) is a paralytic disease which typically results in the inability to speak, use hand signs or gestures, or make direct selections on a computer or a communication aid. Many people who experience ALS have great difficulty communicating and using language. A semantic compaction system based upon the Unity® brand software, accompanied by a word prediction system is being developed and alpha tested. The encoded component of the semantic compaction part of the system is reduced from that found in the 128 location version of Unity. Target training time for the system is estimated at 12 hours.

BACKGROUND

ALS is a progressive disease of motor neurons in the human brain and spinal cord. Paralysis eventuates and can take away the person's ability to walk, eat, speak, work, and even breathe. People with ALS depend on the use of AAC devices to generate expressive language. The devices used by people with ALS include voice output devices, as well as "low tech" devices, such as spelling or word boards.

The cause of ALS is unknown and there is no known medical intervention to arrest the disease significantly at this time. The incidence of ALS is estimated at 2 per 100,000 people. At any given time, there are about six individuals living with ALS for every 100,00 people translating to about 30,000 people in the United States living with ALS (1). About 5,000 people are diagnosed each year (2). ALS can occur from 20 years of age to well into the 80s, although the most common age of onset is the mid-50s. Currently, the life expectancy of someone diagnosed with ALS is two to five years. Half of those affected live longer than three years; only 20 percent live five years; and only 10 percent survive more than ten years (3).

For individuals with ALS and their family members, the journey that ensues in the course of the disease is extraordinarily difficult. Because nearly everyone with ALS has difficulty speaking or loses their speech entirely, addressing communication needs is crucial. As many AAC professionals have discovered, intervention with people who have ALS is different from intervention with most other populations of individuals who cannot or have difficulty speaking. Therefore, it is essential that expressive language programs be developed that specifically address the unique communication needs of individuals with ALS.

STATEMENT OF PROBLEM

Several different augmentative communication manufacturers have designed systems tailored for the needs of people with ALS. These systems both low tech and high have traditionally been based upon the letters of the alphabet because ALS typically strikes in adulthood and most adults already know how to spell. However, letter systems, whether manual, eye gaze, or computer based have certain serious drawbacks. Principle among these drawbacks is the slow rate of communication when letter systems are attached to voice output in the form of speech synthesizers. The increased independence gained through voice output is often negated by the length of time it takes to spell utterances, even with the assist of word or lexical prediction (4).

Systems with semantic encoding such as the various Minspeak® application programs (MAPs) have not generally been prescribed for people with ALS because of the time taken to learn such systems. For semantic encoding to be deemed useful for people with ALS, a radical reduction in the number of hours required to learn such systems is needed.

Second, research with direct selection systems shows that semantic encoding can result not only in a significant reduction of keystrokes (5), but in a significant enhancement of communication rates (6). Scanning systems, as opposed to direct selection systems, however, have different parameters for the measure of rate enhancement. In a scanning system, the steps or selections-scanned-through in order to make a desired actuation must be assessed in terms both of number of steps and amount of time per step.

Two developments in the past five years have had direct impact on the feasibility of using semantically encoded systems for ALS. An increasing sophistication in vocabulary selection has shown clearly that approximately 80 to 85 percent of most spoken language is comprised of fewer than several hundred different lexemes (root words) (7). Such a reduced target vocabulary has made it possible to envision a relatively short training period for teaching and learning semantically encoded lexemes.

The development and patenting of a successful icon prediction approach in which only legally coded icons are available for selection has reduced dramatically the number of steps needed per selection in a scanning system. Coupled with the reduction in the number of words semantically encoded, the icon prediction system produces a radical reduction in the number of steps required in a 128 location semantic system. These two developments taken together open up for the scanner the benefits of semantic encoding for the first time.

DESIGN DEVELOPMENT

Since 1987, the Prentke Romich Company has been developing expressive language. Called MAPs, they have been designed for specific population groups, including preschool children with severe disabilities, school-paged children, and physically challenged adults. The aim of this project is to develop an expressive language program that includes three separate modules. A) A semantic application program uniquely designed for individuals with ALS for use in a dedicated system which includes a word prediction feature; B) A Low-Tech Communication board paralleling the semantic application program for use as a training tool and back-up system for the electronic device; and C) A training tutorial to teach the system.

The electronic ALS system features the semantically/syntactically represented closed-class paradigms (personal, indefinite, relative, and interrogative pronouns, prepositions, conjunctions, modals and auxiliaries) of English, as well as certain common noun, adjectives, adverbs, verbs, and interjections which taken together comprise approximately 80 to 85 percent of spoken language (8).

The word prediction part of the electronic system will feature a large extended vocabulary which will have the capability of excluding from prediction the words already encoded in the semantic section of the system. Preliminary evaluations of the system based upon actuation per word as well as step per word indicates meaningful lowering both of steps and actuations, especially if the scanning technique employed is quarter-row column scanning in which a keyboard of 128 keys is scanned by successive quadrants in a clockwise fashion.

The Low-Tech Communication Board will parallel the semantically encoded electronic system. It will provide all of the frequently used core vocabulary of the application program along with the alphabet and additional conversational control sentences such as "you misunderstood me."

EVALUATION

Two system users in the initial stages of ALS have volunteered to be part of the development project. Volunteer trainers have been selected from a pool of individuals familiar with the parts of speech in English. Closed-class paradigms are being taught before high-frequency open-class paradigm words have been selected. In teaching the closed-class paradigms, the compound modal auxiliary forms of English are being scrutinized to match completeness against utility. For example, "could have," "should have," and "could have been" all occur with a certain regularity in daily speech. Giving each one of these modal auxiliary compounds its own separate representation as opposed to allowing their composition by the user would dramatically reduce both the number of actuations required and the steps scanned for these compounds but would burden the retrieval of the much more frequently used non-compound forms. In other words, "would" would be longer and slow to select, but "would have" would be dramatically reduced both in actuations and steps. These issues cannot be decided on numbers alone. Eventually the feel and the cognitive stress of one maybe greater than the benefits derived from another. Individual preferences and practical considerations expressed by users are also being considered in the overall configuration of the system.

Training time is being isolated from design time in order to assure brief training periods from the start. User's satisfaction is being assessed through interview. The communication board is investigated to determine whether it provides an adequate backup communication system for those times when the individual does not have access to his or her voice output device.

The training tutorial is designed to be used by either professionals or lay persons working with the individual with ALS. The training tutorial includes step by step lessons designed to teach basic operations of the voice output device, the vocabulary in the voice output device, and the use of the low tech communication board. Instructional design strategies are employed to create and field test the materials.

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METHOD

Subjects. The research results reported here are part of a 5-year longitudinal study of communicative development in children with physical impairments who are at risk for being nonspeaking. Children & parents receive 2-4 hour visits in their homes to participate in a variety of cognitive and communicative measures over a period of 18 months each (6 visits every 3 months). The following data are reported on 18 of 30 children, mean corrected age 18.4 mo. (range 12-24). The samples of communicative behaviors and test scores are taken from their first visit only. The children have primary diagnoses of physical impairments and demonstrate risk for vocal expressive development (McDonald, 1980). Children may have secondary diagnoses such as cognitive or sensory impairments (with some useable hearing or vision). The children's average scores on the Battelle Developmental Inventory (age equivalence in months) were: overall: 8.5 mo., receptive communication: 12.4 mo, expressive communication 9.8 mo.

Measurement: The Communicative and Symbolic Behavior Scales (CSBS) (Wetherby & Prizant, 1993) was administered to all children who demonstrated intentional communication, which at the first session included only 18 of the 30 children. The CSBS provides nine communicative "temptations" that prompt children to request and/or comment on play activities, such as presenting a bag of toys and helping the child pull each one out to show adults. Children's communication may be gestural and/or vocal, but must be directed towards an adult to be considered a communicative behavior (e.g. by looking or reaching towards the adult). Communicative behaviors scored from videotapes may represent one of three communicative functions: behavior regulation, joint attention, or social interaction.

Eighteen children's scores on the CSBS were analyzed, with one behavior sample per child. Children's raw scores were converted to scaled scores from 1-5, based on the CSBS norm derived from typically developing children at similar language stages (scaled scores are presumed equivalent across functions and can be compared directly, though not added or subtracted to each other). A Wilcoxon Signed Rank Test compared children's CSBS scaled scores for behavior regulation, social interaction, and joint attention.

RESULTS

Joint attention scaled scores on the CSBS were significantly lower than behavior regulation scores (Z Value: -2.260, $p = .02$). No other comparisons in communicative behaviors were statistically significant. Therefore, children with severe physical and vocal impairments tended to produce fewer joint attention acts than expected relative to their production of behavior regulation acts, across all skill levels included in the analysis. Children who rely on AAC therefore seem to be consistently slower than typically children at similar language stages to use joint attention behaviors to label or show objects. Scanning the data suggests that children monitor parent or adult attention within expectations for their communicative rate (using gaze shifts) but are less likely to act to control a parent's joint attention

DISCUSSION

Theoretical Implications: Young children with physical impairments who are nonspeaking were less likely to direct someone else's attention to an object or activity than typically developing children, and tended to have a greater proportion of their communication represented by behavior regulation. Both joint attention and behavior regulation behaviors were equally physically accessible to the children (e.g. showing for joint attention and giving for requesting require similar physical coordination). The relative limitation in joint attention production may occur for reasons similar to those that explain differences in imitation (Cress, Reynolds & Andrews, 1998), i.e. that both types of behavior represent communication as its own end as a "just because" behavior. Young children with physical impairments may limit their interactive behaviors with motoric "cost" in circumstances without direct functional or communicative benefits. Since joint attention accomplishes little tangible purpose other than sharing activities or information, this may not provide enough of an observable response for children who have considerable difficulty initiating communicative behaviors successfully. As children grow older, and more of their language- or age-matched peers conduct conversations around shared ideas rather than requests within shared activities, a difficulty in expressing joint attention functions may cause difficulties in conversation in addition to those introduced by the augmented communication modality itself.

JOINT ATTENTION AND YOUNG CHILDREN RELYING ON AAC: RESEARCH IMPLICATIONS FOR AAC INTERVENTION

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ABSTRACT

Managing joint attention with communicative partners is essential for successful linguistic communication. For children who use visual systems such as AAC, various factors including partner strategies, environmental constraints and expectations, and children's speed and ease of communication may all influence the effectiveness with which children using AAC learn joint attention control within conversations. This paper compares early joint attention behaviors (e.g. showing an object) in 1- to 2-year-old children with physical impairments based on expectations from typically developing children. Children at risk for being nonspeaking tended to produce fewer joint attention behaviors than expected for their language stages, regardless of their relative language skill. Implications for clinical intervention with young children relying on AAC are discussed.

BACKGROUND

As typically developing children develop beyond their second year, a greater percentage of their conversation revolves around sharing ideas, rather than early emphasis on requesting and rejecting objects of activities. Sharing ideas within conversation requires skills at controlling joint attention, or paying attention to the same thing at the same time, usually initiated by an action of either the child or the parent. Joint attention skills are critical for children at early ages to learn the correct association between words and their referents. Successful language learners acquire very early skills at checking for the directing adult attention (Baldwin, 1995). Responding to joint attention cues from adults (e.g. "Look!!" with a pointing cue) is a good predictor of later symbolic language development in children with disabilities (Mundy, Sigman, & Kasari, 1990).

In classrooms, attention to teacher activity is tacitly expected but rarely taught. This is not unique to classrooms with students relying on augmentative and alternative communication (AAC), but it presents a more complicated issue than for children who are primarily vocal communicators. If children demonstrate difficulty in shifting attention from their AAC system to the teacher's behavior, this will influence their learning and use of new language skills for classroom communication. Many children, particularly children with pervasive developmental disabilities, have difficulty maintaining or effectively responding to joint attention signals from others. In fact, joint visual regard may be actively avoided by children with sensory processing problems.

When introducing new AAC language concepts, particularly new picture symbols, partners often redirect the child's attention to that symbol rather than waiting for them to discover it and what it might mean. However, children learn new vocabulary more effectively when the labelling follow their line of attention than when we try to redirect their attention (Tomasello & Farrar, 1986). For children with visually represented AAC strategies, the ability to successfully shift and control other interactants' attention may influence their skill at communicating with multimodal strategies and shifting from their own communication system to that used by their communication partners. If children demonstrate early difficulty with joint attention behaviors, this could reduce their effectiveness at developing many later communicative skills such as socially referenced conversations, information sharing, or topic maintenance and control.

RESEARCH QUESTIONS:

1. Do children with physical impairments demonstrate joint attention behaviors with equivalent frequency as typically developing children at similar language stages, relative to other communicative behaviors such as behavior regulation and social interaction?

2. What clinical implications for AAC intervention are suggested by young children's patterns of joint attention development and use during nonspeaking communicative exchanges?

Clinical Implications: If children are at risk for "just because" behaviors like joint attention as a corollary of their physical impairments, then particular intervention strategies need to be introduced at very early ages to promote joint attention development and reduce this source of communicative risk. In addition, the communicative and classroom environment needs to reduce as many barriers to joint attention as possible, and provide practice in sharing information that is relevant to children's own actions. The following suggestions are provided for early AAC intervention:

- Provide early emphasis on responsive interaction feedback, in which partners comment on children's behaviors or activity while it is occuring, and help the child shift their attention between objects or actions of focus and the partner's face. Social routines around objects may provide a natural opportunity for child attention to both objects and people within familiar contexts.
- Follow children's attention and label or comment on what they are paying attention to at the time, using the child's own AAC system strategies. We may also use these episodes as teaching opportunities to introduce new symbols or signs, but reduce our verbal redirection of children's attention as much as possible in favor of situationally prompting attention and then providing meaningful labels.
- Include questions like "what's that?" early in children's behavior and/or symbol repertoires, and model these phrases frequently in communicative routines.
- Include words like descriptors, adverbs, and question words earlier on topic boards, and in children's communication systems so that children can make creative and relevant joint attention comments when they may only be able to access a few items at a time.
- Imitating a child's own behaviors is an early strategy for fostering turntaking and new joint attention behaviors. This can be particularly effective for children with PDD (Prizant & Wetherby, 1987). However, children with physical impairment are less likely than language-age peers to imitate behaviors without a functional context (Cress et al, 1998).

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TALKBOARDS: A SOCIAL CONVERSATION AID FOR LITERATE PEOPLE WITHOUT SPEECH

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ABSTRACT

People who are literate but unable to speak can use text-based AAC systems. Entry of text during a conversation is, however, generally too slow for socially effective conversation. Pre-storage of phrases can support much faster responding, provided text is stored within an organizational framework that makes it easy to locate appropriate phrases. TALKBoards has recently been developed as a text storage and retrieval system to run under Speaking Dynamically Pro™. It has features that help a user to make an appropriate response to anything a partner says and to take a full share in the control of conversational direction. Features of the system that permit a relatively fast conversational rate without compromising quality of content are demonstrated.

BACKGROUND

People who, though literate, are unable to speak may be able to communicate using a text-based AAC system with synthesized speech output. Unfortunately, the delay between formulating a response and its readiness for speech output is generally too long to sustain effective social conversation when text is entered during a conversation. Even with word prediction, conversational rates with text entered during a conversation rarely exceed 2-15 words per minute and users frequently resort to telegraphic phrases. They also tend to be forced into a passive role in which they do little more than produce 'yes' and 'no' responses to their partner's questions. It is rare for users to be able to take a full share in the control of topic content or in the management of turn-taking.

An alternative strategy is to pre-store text ready for retrieval in whole phrases during a subsequent conversation. If only a few messages are stored, one can be located quickly when it is needed. As the number of stored phrases increases, however, retrieval difficulties again result in long delays. In addition to the retrieval problem, there is the difficulty of anticipating what directions a conversation might take and, even when a particular topic has been anticipated, the stored phrases on the topic are unlikely to provide precise responses to specific things that a partner says.

OBJECTIVE

A major goal was to develop a text-based AAC system that would permit extensive pre-storage of phrases of a kind that would allow the user to make acceptable 'off the shelf' responses to most things that a partner might say in an unrestricted conversation. A related goal was to provide an organizational framework for storing the phrases that would aid their rapid retrieval and, at the same time, enable the user to take a full share in controlling the direction of the conversation. It is recognized that, during a conversation, there will be a shifting balance between the competing demands of speed and felicity in responding to what a partner says. Another goal, therefore, was to achieve an effective dynamic balance between these requirements. It will be demonstrated how the above goals have been met using features that have been developed and evaluated in prototype TALK systems over the past few years, and that have now been implemented in the commercially available AAC system called TALKBoards, which runs under Speaking Dynamically Pro™.

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RATIONALE

The approach has been to focus on the social and personal goals that motivate casual conversation and to attempt to model pragmatic aspects of natural, unaided conversation that seem to contribute to these goals for participants (1, 2, 3). This approach is justified by the observation that much casual conversation is concerned less with the accurate transmission of information than with enjoyment of the interaction, creating a favorable impression, and so on. Pragmatic aspects of natural conversation that have been modelled in TALKBoards include the following:

1. Topic development typically progresses in a series of small steps, with both partners initiating perspective changes that move the topic forward. Common perspective shifts are between *talk about one partner* and *talk about the other*, between talk about events and views relating to the *past*, *present* and *future*, and between the *what*, *when*, *how*, *why*, etc. of events or views.
2. In order to maintain conversational flow, when it is not necessary to provide a very specific response to something a partner says, people often respond with a rather general 'off the shelf' comment, such as 'that's life isn't it', rather than taking the time to generate a novel response.
3. Much conversational content is recycled, particularly idiomatic phrases and personal narrative.
4. There is much use of supportive feedback during a partner's turns at speech.
5. Apologies and clarifications to avoid misunderstandings or confusions are delivered promptly.

IMPLEMENTATION

TALKBoards has the following features:

1. A central screen area contains *speech buttons* on which the user enters candidate topic phrases.
2. Which phrases are displayed is controlled by means of *perspective buttons* down the left side of the screen. There are three intersecting perspectives: *Person* (me, you), *Issue* (what, where, when, why, how, who), and *Time* (past, present, future). A separate board is available for each possible combination of perspectives. For example, if the *me/what/past* perspective buttons are clicked, a board containing phrases relating to 'recollections of, or views about, things that have happened in the user's past' will be displayed. The user can therefore get to any stored topic content with a maximum of three moves. This organization, which has the merit of being stable over all topics (4), provides a navigation system that helps users to find their own stored phrases relatively rapidly in order to (a) respond in good time to partners' questions or comments and (b) to move the conversation in directions for which they have appropriate topic content stored.
3. At the top right of the screen there is a general comment menu (*Sympathy*, *Hedging*, *Questions*, etc.): when one of these categories is selected, a pop-up menu displays general comments that the user has stored. For example, the *Sympathy* category might contain phrases such as 'What a shame', 'That's too bad', 'I'm really sorry to hear that', etc. The point about these readily available phrases is that they can provide appropriate responses to many different things that a partner might say. They are effective for maintaining conversational flow when a more specific response is not available (5).
4. Buttons for even more rapid (quick-fire) responses are available down the left side of the screen. These operate in two modes which the user can toggle between: (a) random selection from pre-stored options and (b) pop-up menus, as for the general comments. The random mode provides for very rapid, but non-repetitive, output of one of several equivalent responses. For example when the *Good* quick-fire button is clicked while in the random mode, any one of the following might be output: 'that's great', 'fine', 'good' etc. If the same button is clicked while in the pop-up mode, a more tailored response can be selected from a range of non-equivalent responses (e.g.

'Terrific', 'Not bad', 'Absolutely amazing', etc.). Quick-fire responses allow users to make well-timed feedback remarks and to repair misunderstandings without delay.

5. Administrative buttons for managing the input, location and editing of text are at the bottom right of the screen, together with an on-screen keyboard button which provides word prediction support for the entry of text to be stored or for the on-line entry of text during a conversation.
6. Buttons for selection of *Greeting* and *Goodbye* boards are provided along the top of the screen, together with a *Stories* button facilitating adjacent entry of phrases likely to be output in a fixed sequence, a *Switch* button that allows the user to move easily between sets of boards prepared for various people, contexts or topics, and a temporary *Storage* button to avoid disruption of a conversation while deciding where to locate new text entered during the conversation.

EVALUATION

Studies with speaking and non-speaking users have found that conversational rates (including pre-speech pauses) between about 50 and 80 words per minute are possible using the TALK system, and enjoyment and social competence ratings have been found to increase with conversational rate (6, 7). Users have been shown to take a full share in the control of topic direction and high ratings of the quality of content of TALK-aided conversations have been reported (1, 8). In a recent study, a TALKBoards user, with the free choice of entering new text during conversations or using pre-stored content, chose to enter new phrases on only about 4% of her turns at speech with new partners and on about 7% of occasions with a familiar partner (3). For some literate non-speaking people at least, TALKBoards appears to meet the objectives that motivated its development.

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PICTALK FOR SOCIAL CONVERSATION

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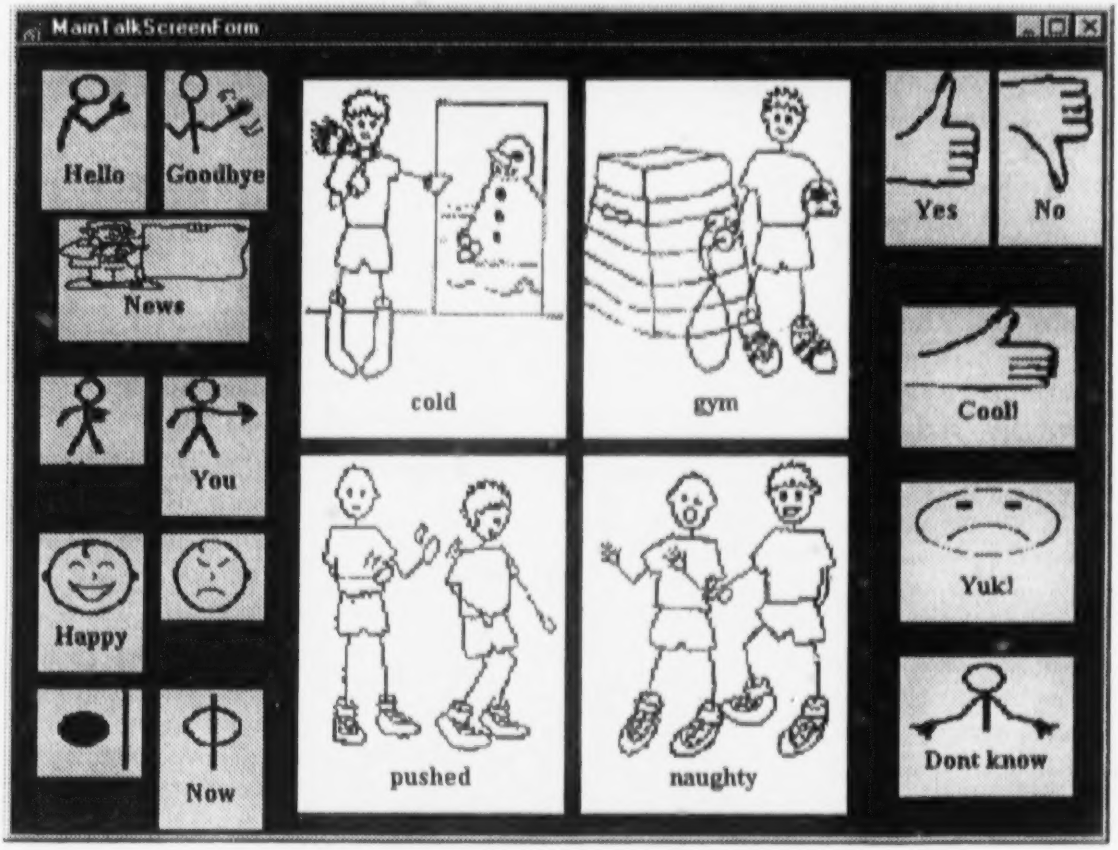
ABSTRACT

PICTALK is a computer-based system for supporting casual conversation by people who cannot speak and who are also unable to read. The available phrases to be spoken are organised in a framework of intersecting perspectives designed to model the flow of conversation. In addition, generic smalltalk phrases are available for use when specific content is not available. These structural features in the system interface are designed to support conversation flow. PICTALK also offers a simple editing system to allow users to prepare for a conversation by selecting phrases they think they would like to say.



OBJECTIVE

We have been developing a conversation aid, PICTALK (1), to support the casual conversation of people, particularly children, who can neither read nor speak. It is important that

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children who have no speech or whose speech is so impaired that they cannot readily be understood have the opportunity to develop social and conversation skills. PICTALK is a simplification of the TALK system (2, 3), a conversation aid for people who are unable to speak but who are able to read. The interface for PICTALK (see above), is designed to be less complex than TALK while retaining key structural features that allow users to have socially satisfying conversations. These features are designed to support social aspects of conversation rather than the delivery of information.

DESIGN

Each picture on the PICTALK screen pictured above acts as a 'button' that, when selected, carries out an action. The action that a button carries out depends on which part or region of the screen the button is in. The screen is divided into 3 regions. From left to right in the picture, these are: a conversation perspective section, a main speech section, and a quick fire speech section.

The sections on the left and in the middle operate together. In the main speech region, in the center of the screen, the buttons speak phrases with quite specific content that the child has pre-selected for a particular conversation. In the perspective region on the left, the buttons are organised as a set of intersecting perspectives that can be used to change the specific content items that are available in the central region. These intersecting perspectives provide an organisational framework for the pre-selected phrases that are intended to match the flow of social conversation. In PICTALK, these perspectives are: (i) you, me (ii) happy, sad and (iii) past, present-future. In the PICTALK screen pictured above the me/sad/past perspectives have been selected and the phrases in the center of the screen are appropriate for these perspectives, e.g. “I was naughty yesterday”, “I pushed my friend in the playground”. As a conversation flows, it is likely to move from one perspective to another. Each of these perspective changes requires only one button press. For a child-adult conversation, the flow of conversation might be from talk about things that the child was sad about in the past (me/sad/past perspectives) to things that the child was happy about in the past (me/happy/past perspectives) to things that the child is happy about now (me/happy/present perspectives). ‘Hello’, ‘goodbye’ and ‘news’ buttons also act like perspectives, giving the child access to phrases for beginning and ending a conversation and to the child’s most exciting, topical events.

In the region on the extreme right of the screen, each button speaks a quick-fire phrase (or a random phrase selected from a set of similar quick-fire phrases). These quick-fire phrases are generic smalltalk phrases that are likely to be useful during any conversation. The quick-fire buttons are unaffected by any changes in perspective and are available at all times during a conversation. Much of children's conversation consists of generic smalltalk phases of the kind that are typically included on these quick-fire buttons (4). These buttons support conversation flow, especially when a suitable specific response to something a partner says is not available. They could also be chosen to support important pragmatic features that are present in even young children's conversation, such as requests for clarification or notices of topic shifts (5).

There is a separate editing facility in the PICTALK system that allows the child to pre-select potential conversation fragments to be included in each perspective. These fragments will initially have to be constructed by someone other than the child, but the child can then select which to use when planning a conversation with a specific conversational partner in mind, for example, when thinking about what to tell Granny. Then, during the conversation, these pre-selected items should be easy to find using the appropriate PICTALK perspectives.

DISCUSSION

Of course, it is difficult to really plan a conversation and the PICTALK user is unlikely to find exactly what he or she would like to say. However, the PICTALK system should help a child user to find something to say which is sufficiently appropriate to maintain the interaction. There is evidence also that young children may be relatively unresponsive to their partners (5). This may have the fortuitous consequence that failure to locate precisely the correct thing to say may be less disruptive of the conversational interaction so far as the child user is concerned. In short, having selected an appropriate perspective, usually any of the available phrases will do. Further, from McTear's (5) work, it seems plausible that children may be able to recognise a suitable utterance as appropriate if it is suggested, even if they are unable to recall and locate it. Therefore, if the child selects an appropriate perspective and a suitable utterance is available in that perspective, then the child may be able to recognise it as such and select it.

The prototype PICTALK system is currently being evaluated and it is anticipated that a commercial implementation will follow.

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Frametalker: A Communication Frame And Utterance-Based Augmentative Communication Device

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ABSTRACT

This presentation describes the design of an utterance-based communication device utilizing a *Communication Frame* approach to allow the selection of natural language utterances. Communication frames possess a schematic structure representing the situational structure off communication events which can be used to organize semantically and functionally related utterance that tend to arise in typical instances of talk.

BACKGROUND / STATEMENT OF THE PROBLEM

This project involves the implementation of a *Communication Frame* approach that provides organizational structures and methods to allow rapid and efficient selection of target natural language utterance constructions. A system, method and database has been developed for organizing and selecting natural utterance constructions to be used in typical contexts of interpersonal communication. The design is based on the insight that efficient utterance selection can be achieved by an interaction of three types of communication knowledge: (a) knowledge of schematic communication structure of typical contexts of communication (frames); (b) knowledge of typical linguistic structures which individuals use in given contexts of communication (constructions); and (c) knowledge of the semantically related lexical items which will fill the same slot in particular contextualized linguistic structures (fields).

APPROACH

A communication frame can be defined as an organized collection of language structures that an individual would typically use with a given interlocutor, in a specific context of communication, and where a particular topic or situation is in focus (e.g., having a headache, going grocery shopping, the recent football game, greeting and leave-taking) communication (1,2,3,4). A communication frame consists of several parts including (a) a topic domain and frame hierarchy, (b) component frames and (c) utterance constructions and lexical fields (5). A cluster of individual communication frames that share similar generic topic interests that share a degree of internal organization is called a topic domain (e.g., mealtime, illness, shopping). A topic domain typically consists of a hierarchical structure consisting of different frame levels, extending from superordinate frames to subordinate frames. A schematic of the structural characteristics of a topic domain and related frames are presented in Figure 1.

Here we can see that the topic domain consists of a set of hierarchically organized frames addressing talk about "aches and pain". The most abstract or superordinate levels contain talk about the generalities of illness. Descending the hierarchy, individual frames become more specific, with "backache" and "headache" representing the basic categories. Subordinate frames address the subtypes of a specific illness (e.g., talk about sinus and migraine headaches).

Each communication frame typically possesses an internal schematic structure, involving component frames and utterance constructions (Figure 2). Component frames are smaller sets of meaning structures that are dedicated to uniquely identifiable typical subtopics or distinct situational portions within the larger communication frame (e.g., 'severity' versus 'cause' of pains). The schematic structure that binds component frames together will vary according to the type and nature of the communication frame (i.e., Does it have a chronological structure, a partonymic structure, a hierarchical structure, a cause and effect structure?). Component frames contain utterance constructions. In the Figure 2, the component frames of the backache frame (indi-

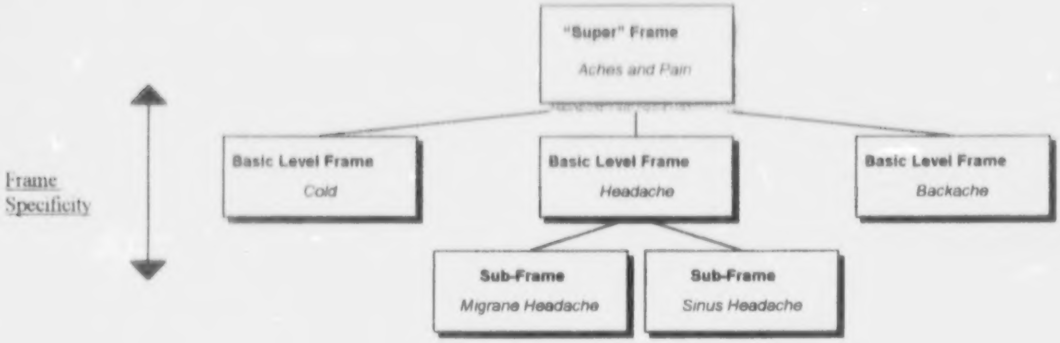

Figure 1: Hierarchical organization of a communication frame for the Illness topic domain

Backache Frame

Component Frame 1	Component Frame 2	Component Frame 3	Component Frame 4	Component Frame 5
Symptom	*Location*	*Cause*	*Time*	*Remedy*
I feel sore *	My lower back hurts	I fell down.	It just started.	Do you have any pills?
It's a sharp pain.	Next to my shoulder	I worked too hard.	It started an hour ago.	Aspirin hurts my stomach.
I've got a backache	All over.	I was bending over.	I get them all the time.	I need to see my doctor
It hurts to walk	My back.	I don't know.	It keeps coming back.	I need a massage.

Figure 2: Component frame structure and prototypic utterance constructions for the frame *backache*. * underlined words indicate variable slot with a default filler

cated by underlined label) contain semantically and functionally related utterance constructions which flesh out the different subtopics (or conversational moves) that tend to arise in typical instances of talk about backaches.

Utterance constructions are the representations of the individual communicative acts that are relevant to a given communication frame. Usually, an utterance construction consists of a variety of linguistic elements from single words through to multi-clausal structures. An utterance construct may contain a variable slot with an attached lexical field. This slot contains default filler whose selection is based upon its importance or frequency of use in that specific communication context. Alternative lexical items are represented in terms of a semantically-based lexical field associated with the utterance construction. Thus, each utterance construction in combination with its associated lexical field (i.e., group of semantically related terms) can be used to generate a potentially large number of different utterances.

IMPLICATIONS / DISCUSSION

The features of the communication frame can be used to structure a database of utterances and develop navigation paths between frames. These categories and navigation paths are based on empirically derived cultural and linguistic knowledge representations. The communicator then efficiently navigates the AAC system using some partial knowledge of their native language system together with normal human inferencing abilities. The resulting utterance-level frame-based technology allows an individual to efficiently select among natural language constructions related to typical contexts of interpersonal communication. A four to six - fold increase in communication rate is estimated for this approach since it takes only one to four selections to retrieve a particular utterance. This is compared to present word-based systems that take between 15 to 25 keystrokes to perform the same task. For the 100 or so topic domains to eventually be mapped out, it is estimated that a communication device utilizing this approach could generate several hundred thousand unique utterances.

The Frametalker software could provide the user with a coherent set of utterances, engineered for the particular communication situation (i.e., communication frame). The display receives data on the form, content and organization of the communication frame, then displays the communication frame accordingly. At this point the user may interact with the communication frame, either speaking or modifying the utterance, or navigating between frames.

The default features of any particular frame will be matched to the appropriate pragmatic, topic and semantic specificity dictated by the situation. For example talk about having a "headache" would, by default, contain utterances oriented to talk about one's self in the present tense. The user systematically shifts the pragmatic aspects of the communication to talking about the addressee's headache and/or to talk about a past headache. This "shift" would apply to the relevant pragmatic characteristics of all utterances in the specific communication frame until the user makes another shift or navigates to another communication frame. Similarly, the user could respecify the communication frame to be more specific (e.g., sinus headache), more general (e.g., being sick), or to a related illness (e.g., a cold). Finally, the user is able to alter the semantic content of a particular utterance by changing the default value of the lexical slot item. In Figures 2 & 3, for example, the user of this interface could directly communicate, *I feel sore*. If the user wished to convey a different feeling, he could call up the lexical field associated with the utterance construction (i.e. body-feelings) to develop a more appropriate expression (e.g., *I feel nauseated*). It is also important to note that any systematic transformation of the communication frame will maintain much of the original frame organization, thereby making the interface easier to understand.

The means by which a user makes these selections (e.g., touch item, select button, type code) depends on the particular means of access and user interface employed. It should also be noted that any full implementation of an augmentative communication device incorporating Frametalker should include a means to spontaneously construct utterances through spelling, word prediction and/or encoding. Also, Frametalker could easily be configured to provide a reduced set of options for individuals with significant language and/or cognitive challenges.

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SENTENCE GENERATION USING THE VERB PREDICTION FOR KOREAN LANGUAGE DISORDERS

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ABSTRACT

In this paper, we developed the augmentative communication system that generated the well-formed sentence in Korean language by symbols for people with communication disorders. The system should place a minimal burden on the users. The augmentative communication aids combine the benefits of pre-stored messages with linguistic prediction capabilities to create unique acceleration techniques. When the users press symbols, the software predicts verbs, which are displayed in scanning modes based on semantic marker. In order to generate the well-formed sentences, adequate postpositions follow it according to verbs for each input word.

BACKGROUND

AAC (augmentative and alternative communication) is an area of clinical practice that attempts to compensate (either temporarily or permanently) for the impairment and disability patterns of individuals with severe expressive communication disorders (i.e., that severely speech-language and writing impaired) (1). Computers and computer-based technology have become an integral part of the lives of many individuals with disabilities. One of the most common activities that computer can assist is the sentence generation. People who can not accurately control their extremities (due to disabilities such as cerebral palsy and spinal cord injury) use computers as writing tools. People whose physical disability restricts their spoken output may use a computer as communication prosthesis. In both cases, the sentence generation is a necessary activity that can be physically demanding. It should be made as easy for the users as possible (2).

Non-speaking persons who use printed alphabet letters as symbols are using a traditional orthography system. It is difficult for many non-speaking persons to learn to use written letters for communication. One of the factors that separate high technology communication aids from low-technology is the use of pre-stored messages and message prediction techniques (3).

Both methods are called acceleration techniques because their purpose is to increase the speed of communication. Most of the word-based techniques use a frequency of use formula for prediction. The software presents word choices based on previously written words. Recently it has been developed by applying information frequently used by users and syntactic word ordering rules for prediction.(3) (4).

In this paper we proposed augmentative systems for sentence generation by symbols in Korean language.

RESEARCH QUESTION

The objective of this study is to develop the augmentative communication system that generated well-formed sentences in Korean language. In generating sentence, symbols and symbol sequence are used to represent lots of vocabularies easily within the restricted domain.

There is a limitation of requiring learning and guess in such a dynamic and static system. So we developed systems that predicted verbs suitable for input words based on semantic marker to enhance communication rate.

METHOD

Vocabulary Selection

It is important to select required vocabularies after location domain is determined in consideration of users' environment since this device is used as portable augmentative communication system. Vocabulary items can be divided into two basic types; Core and Fringe. 'Core' can be defined as words which are used frequently across situations, whereas 'Fringe' words are those which are used in specific situation

Typically they are nouns and verbs, and we selected simple sentence. Fig.1 shows a representation of a word for an icon within home domain. If mouse cursor is located at the desired icon, the word is displayed below the icon and then the word is represented in the input words by clicking the mouse one time.

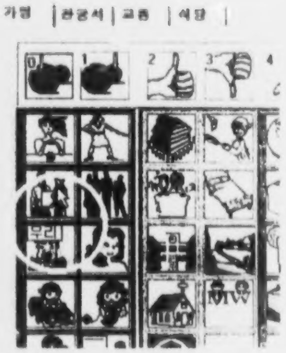
가정
관공서
교통
식당
0
1
2
3
4
우리

Fig. 1 A representation of word for icon

Semantic Compaction

The structure of the system is divided into two large groups, i.e., a dynamic system and a static system. The dynamic system has an advantage of easiness of learning, but it can not express many vocabularies. Therefore the static system introduces the concept of semantic compaction and thus many vocabularies are included in symbol sequence. For example, the APPLE+VERB to code the code 'eat'. Similarly APPLE + ADJECTIVE gives 'hungry', and APPLE+ADVERB gives 'hungrily'. But semantic compaction has a limitation for individuals with cognitive impairments.

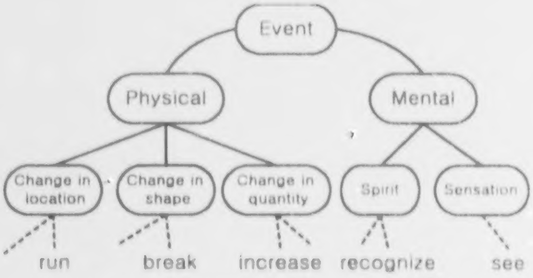
Event
Physical
Mental
Change in location
Change in shape
Change in quantity
Spirit
Sensation
run
break
increase
recognize
see

Fig. 2 The example of the hierarchical relations and semantic marker

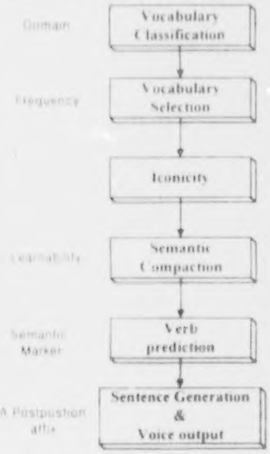
Domain
Vocabulary Classification
Frequency
Vocabulary Selection
Iconicity
Learnability
Semantic Compaction
Semantic Marker
Verb prediction
A Postpostion affix
Sentence Generation & Voice output

Fig. 3 The block diagram of Sentences generation

Verb Prediction

One word has '+' or '-' in semantic marker. This semantic information can be represented with logical formula. Verbs can be decided according to subjects and objects. Fig.2 shows the examples about the hierarchical relations and semantic marker. Different from English in word order, Korean put the verbs in the last of sentence. Therefore if symbols are input, verbs are predicted. For example, if 'Tom' is input as a subject and 'cup' is input as an object, it is analyzed like this: 'cup' is physical and a kind of 'tool' and then system predicts the verbs then can be an object like a cup. Therefore the word 'break' can have predicted, but the word as like 'run' can't be. Because 'break' means the change of type, but 'run' means the change of location. When a symbol pressed, a word is displayed and a verb

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is selected. Then the postposition is affixed by the word and then a well-formed sentence is generated. Simultaneously through TTS (Text To Speech) method, the voice is output.
Fig. 3 shows the block diagram from the vocabulary classification to the sentence generation. In this paper, we focus on 'Universal Grammar' independent of a special language.

RESULTS

The system includes parts of display, control and contents. The display part includes input words and sentence. The control part includes the place domain and function of verbs, adjective, adverb and can include the core vocabulary. In the contents part, the icons for nouns of actor part and objects is located at left side and icons for verbs is located at right side according to the frequency of words. And we had the voice output for language disorders to be able to communicate with normal people naturally. Fig.4 shows the structure of the system in the home domain. Borland C++ Builder accomplished the program.

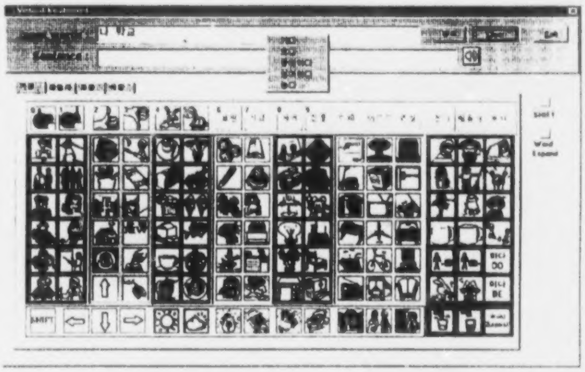

Fig. 4 The structure of system

DISCUSSION

In this paper, the augmentative communication system was designed. The system generates sentence by symbols for language disorders. It includes the semantic compaction in order to overcome the restriction of space. Verb prediction was used to enhance the communication rate. The system can be used as the writing tool for people who could no use their fingers freely. Symbols have been described in terms of their 'iconicity' (ease of recognition). Also the iconicity of symbols makes keystrokes easy and this approach is useful in promoting literacy. It is thought that this way helps for children to increase power of vocabulary.

For the future the human-computer interaction must be studied in the design process. Also if the speed of augmentative communication device is enhanced and the algorithm on the well-formed sentence is improved, it is expected that the augmentative communication system will be more effective.

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A TALKING DEVICE FOR MUTE ADULTS

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ABSTRACT

A programmable talking box has been designed for a young man who cannot speak. The unit can record and play back sixteen separate messages. The talking box is a portable device that an adult could use to convey messages.

BACKGROUND

The technology behind voice record and playback integrated circuits has grown dramatically in this decade. In recent years, voice record and playback chips have been added to products such as cellular phones, clocks, and greeting cards.[1] Though these products use the human voice as an enhancement, voice is not their central feature. The central feature of a talking box, however, is to record and play back the human voice.

In 1991, Doug Heifner, Sr. asked the Assistive Technology Program (ATP) to design a talking box for his son, Doug Heifner, Jr., an autistic child with full mental capabilities. The device was completed and delivered. In January of 1998, Doug Heifner Sr. asked ATP to design a new device for his now 18-year-old son. He made the second request because his son had outgrown the original device. The original unit was geared toward a boy in grade school. It was bright and colorful. Also, due to its size, the original device could not be carried around easily.

STATEMENT OF PROBLEM

The goal of this project was to design an easy to use talking device that can be kept on an adult's body and be used to relay voice messages.

RATIONALE

The first phase of this project consisted of a meeting with the client to determine in what ways the new design would differ from the old design. The exterior of the old box was bright and colorful. It was appealing to the client when he was in grade school. The original talking box looks out of place in the hands of a young man. The new box should look like a useful device rather than a toy.

DESIGN

The memory of the voice record and playback chip was separated into 16 sections. Pressing one of the 16 buttons on a hex keypad accesses each memory section. In the circuitry, the keypress gets decoded into a four-bit binary number. These binary digits become the address inputs of the voice chip. Since the circuitry utilizes direct addressing techniques, the 16 messages can be recorded or played back in any order. The same keypress that loaded the address bits initiates the playback or record action.

A switch on the microphone determines whether the device is in the record or playback mode. Since the microphone is detachable and is normally in the off state, it is not possible to enter the record mode without the microphone. Since the microphone is required to record a message, it is impossible to accidentally record over a message.

Since the talking box is a portable device, rechargeable batteries power it. The talking box was designed to draw as little current as possible. The use of sleep modes and CMOS integrated circuits causes a minimal amount of current to be drawn, maximizing the time between battery charges.

The voice record and playback chip has a low-power, sleep mode. Taking advantage of the sleep mode eliminates the need for an on-off switch. The absence of the switch allows the device to be used without any sort of initialization. A single keypress allows the user to activate the device. Eliminating the switch is important because it makes the unit more convenient to use. The user does not have to fumble with a switch to turn it on. The talking box is always ready to work. If the user of the device finds it easy to use and easy to keep on the body, it is more likely that the device will be integrated into the user's lifestyle. The box then becomes a convenient way to interact with others.

DEVELOPMENT

To be sure that the circuit would work, it was prototyped on a breadboard. After making a few adjustments, the circuit was synthesized on a copper-clad board. Then, the creation of the box took place. Creating the box included attaching the keypad and providing a jack for the microphone and a jack for the battery charger to plug into.

The keypad connects to the device by an eight-wire-wide strand of ribbonwire. The ribbonwire gives the device flexibility. It allows the user to place the box on one area of the body and put the keypad on another. For this project, it was decided that the box would be placed in a pouch and hung from the client's belt. From there, the keypad would either be placed into the breast pocket of a shirt or bundled up so that it could be tucked away in the pouch.

EVALUATION/DISCUSSION

At 6x3x2 inches in size, the new device, Figure 1, is smaller than the original. When it is attached to the user's belt, the device looks like a large cellular phone.

The talking box is easy to use. To record a message, the user plugs the microphone into the talking box and turns it on. When the microphone is on, the device records whatever the user's surrogate speaker speaks into the microphone while any button on the keypad is held down. When the microphone is off, the device plays a message when a button on the keypad is briefly pressed.

Recharging the batteries of the new unit is a simple process. The user plugs one end of an AC adapter into the talking box and the other into a standard wall outlet. It takes four hours to fully charge the batteries.

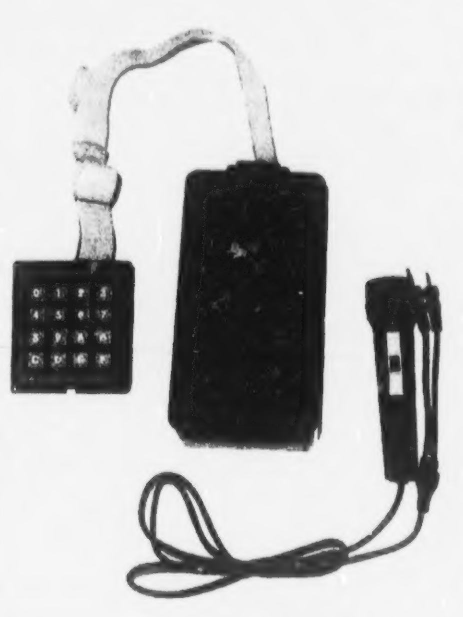

Figure 1: The Talking Device

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ACKNOWLEDGEMENTS

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INVESTIGATING THE PERFORMANCE OF SEVERAL AAC USER MODELS

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State University of New York at Buffalo
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ABSTRACT

Several AAC user models were evaluated to investigate their accuracy in predicting user selection time. User models and computer simulations are useful for designing and forecasting performance of AAC systems. Experimental data was collected from two users engaged in direct selection. Parameter estimation and optimization methods were combined to obtain parameters for four models. The models (from the 1990 paper of Levine and Goodenough-Trepagnier) predict the time needed to transition from one selection to the next by considering such factors as distance, target size, and angle of movement. The modeled selection times were compared to the actual times for over 15,000 selections. On average, the error in the model predictions exceeded 30%.

BACKGROUND

Many AAC devices use custom interfaces that are designed to increase the user's communication rate. Highly probable characters or words may be presented in more propitious locations for efficient user selection. By decreasing the physical effort required for each selection, the user's communication may be accelerated. For example, the traditional typewriter keyboard is organized with a QWERTY layout. For someone who is generating text using direct selection, an alternative layout that keeps frequently used keys in close proximity may yield a higher communication rate. Based upon this criteria, the QWERTY layout is not optimal. Clinicians designing systems are faced with the task of determining what types of layouts will assist users and how various technologies will impact the user's performance. Flexible AAC devices add to the challenge by offering numerous combinations of acceleration techniques and interface possibilities. Additionally, the mental and physical abilities of users can vary widely, further increasing the complexity of the design process.

Computer simulations have the potential to assist clinicians when assembling devices that are specifically tailored to the needs of a particular user. Simulations can be used to intelligently configure and test numerous combinations of AAC technologies in a much shorter period of time than if tested manually. The key to making this process effective is the development of accurate models which can mathematically represent the user and simulate communication tasks.

For many AAC users, communication rate is the single most important factor in determining the efficacy of a device. The time it takes a user to select each letter or language element from the interface is directly related to the overall communication rate. The models evaluated in this investigation predict selection time, T, using several motor-related elements as the basis for the models. Starting with the simplest of models — using the average time as a prediction for all selections — they increase in sophistication to include factors such as distance, angle of movement, and target size. Model 1 serves as a baseline for comparison while models 2-4 were obtained from (1). The models are described mathematically below. Estimated parameters (a, b, c, ϕ, and ε) are in lower case and input variables (A, W, and β) are in upper case.

1) $T = a$
2) $T = a + bA$

3) $T = a + bA + c(1/W)$

4) $T = a + bA[\cos^2(\beta - \phi) + \varepsilon^2\sin^2(\beta - \phi)]^{1/2} + c(1/W)$

where the inputs are:

A = the distance traveled to make the selection

W = size of the key or target selected

β = angle of movement

Model 1 uses the average selection time as its prediction for all selections. Although it ignores the dependencies of distance (models 2,3,and 4), size (models 3 and 4), and direction (model 4) that Fitts (4) and Rosen and Goodenough-Trepagnier (5) have identified, it serves as a reasonable baseline from which relative performance measures can be calculated.

RESEARCH QUESTION

Given that modern AAC devices can incorporate a multitude of technologies aimed at increasing communication rate, clinicians are asked to provide customized devices that are tailored to the needs of individual users. User models can assist in identifying effective blends of new and existing technologies through simulation. The identification of accurate models is an important part of this process. This research was conducted to investigate the performance of several user models by comparing the model predictions to actual user selection times.

METHOD

An in-house AAC software package was used to collect the direct selection data during an unrelated experiment. This system has the capability to record log files that track the time, location (position on the screen), and type (character, shift, backspace, etc.) of all user selections made, providing the data necessary to investigate the four models. Configured with a simple graphical interface (shown in Figure 1), able-bodied individuals used a mouse pointer to perform direct selection while transcribing text during multiple sessions. Log files recorded over 15,000 selections during these experiments.

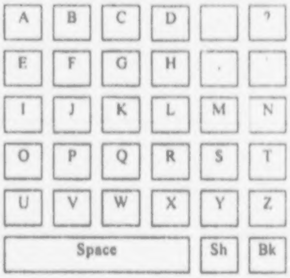

FIGURE 1: Simple interface

Parameters for models 1 through 3 were identified using a simple least squares estimation procedure (2), while the non-linear model 4 required a combination of least squares and Powell's method of optimization (3) to determine its parameters. All parameters were optimized to minimize the error between the model output and the actual times recorded for each selection.

RESULTS

Table 1 shows the results of the study. For each model, the optimal parameters and a measure of the model's average error are presented. Average error provides a single measure of performance that can be used to compare models, it is defined below.

$$\text{Average error} = \frac{1}{n}\sum_{i=1}^{n}\frac{|\tilde{y}_i - \hat{y}_i|}{\hat{y}_i}$$

where: n = number of data points (selections)

$\tilde{y}_i$ = measured T for selection i

$\hat{y}_i$ = model predicted value of T for selection i

Test Subject	Model 1	Model 2	Model 3	Model 4
	$T = a$	**$T = a + bA$**	**$T = a + bA + c(1/W)$**	**$T = a + bA[\cos^2(\beta-\phi) + \varepsilon^2\sin^2(\beta-\phi)]^{1/2} + c(1/W)$**
Subject A	$a = 0.867$ avg. error: 45.22.%	$a = 0.602$ $b = 6.10 \times 10^{-4}$ avg. error: 40.24%	$a = 0.601$ $b = 6.06 \times 10^{-4}$ $c = 0.339$ avg. error: 40.21%	$a = 0.456$ $b = 1.59 \times 10^{-3}$ $c = 0.214$ $\phi = 103^{\circ}$, $\varepsilon = 0.35$ avg. error: 35.37%
Subject B	$a = 0.550$ avg. error: 48.32%	$a = 0.294$ $b = 6.53 \times 10^{-4}$ avg. error: 36.66%	$a = 0.293$ $b = 6.51 \times 10^{-4}$ $c = 0.167$ avg. error: 36.66%	$a = 0.231$ $b = 1.21 \times 10^{-3}$ $c = 0.121$ $\phi = 101^{\circ}$, $\varepsilon = 0.47$ avg. error: 32.62%

Table 1: User model parameter estimation results

DISCUSSION

The average errors of models 2-4 are significantly less than that for model 1, with the most sophisticated (model 4) yielding an improvement of 9.85 and 15.70 percentage points for subjects A and B, respectively. The data showed a relatively insignificant improvement of model 3 over model 2. However, one should not discount the importance of target size (4). With the exception of the space key, the layout used for data collection had graphical keys that were all the same size. Since this data was collected during an unrelated experiment, target size was not a consideration when designing the interface. A study utilizing varied key sizes might reveal more significant target size effects. The results of this investigation suggest that user models can be improved to increase the accuracy of the predicted selection times. For simulations to prove useful in assisting clinicians in device prescription, such improvements will be necessary.

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EFFECTS OF NGRAM ORDER AND TRAINING TEXT SIZE ON WORD PREDICTION

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ABSTRACT

The prediction of probable words for more immediate selection has proven a valuable technique for augmenting the communication of persons with disabilities. Statistical prediction techniques have been limited to completion of the current word and prediction of the subsequent word. This study quantifies the impact of adopting higher-order prediction techniques that rely upon increased word context. Additionally, it establishes the dependence of performance upon the size of the text used to derive the statistical database The results suggest that adoption of higher-order techniques and larger databases can increase keystroke savings by more than 7.5 percentage points.

BACKGROUND

For more than 20 years, word prediction has been an important technique for augmentative communication. Traditional systems have used word frequency lists to complete words that the user has already started spelling out. However, more sophisticated predictive techniques based on the previous word or on syntactic rules have appeared in the last few years. More advanced prediction methods can provide higher degrees of keystroke savings (percentage of keystrokes eliminated by integrating the prediction method) which may translate to faster communication rates. Although several researchers have noted that the increased cognitive load associated with word prediction may interfere with rapid communication, recent findings have hinted that more accurate predictions may more than compensate for these cognitive loads (1).

The advantages of increased predictive accuracy are not limited to the keystroke savings provided by word prediction lists. By providing orthographic and grammatical cues, effective word prediction can improve the quality (as well as the quantity) of message production for young people, persons with language impairments, and those with learning disabilities (2). Additionally, word prediction techniques can be used to disambiguate sequences from ambiguous keypads, correct spelling errors, and provide more accurate character predictions for scanning interfaces (3).

By exploiting the current sentence context using statistical techniques, a prediction system can provide more appropriate word choices to the user. In *ngram* word prediction methods, the previous n-1 words are used to predict the current (n^{th}) word. The ngram data is collected by counting the occurrence of each unique n word sequence in a large corpus called the *training text*. For augmentative communication applications ngram techniques have been limited to unigram (n=1) and bigram (n=2) word prediction, although trigram (n=3) and higher ngram orders are commonly used in other language-related fields such as speech recognition and machine translation (4).

For ngram orders higher than unigrams (n>1), there is such a large number of linguistically valid n word sequences that even in extensive training texts some sequences will not appear, or will occur too infrequently to provide statistically meaningful data. A prediction system must therefore temper its higher order ngram predictions with lower order, more reliable, ngram predictions. This is generally done through a linear interpolation process wherein predictions from each ngram order are weighted by a different factor (4). Even when using this compensatory method, however, the effectiveness of an ngram prediction model is highly dependent upon the size of the training text.

RESEARCH QUESTION

The objective of this study was to establish a set of performance measures for word prediction using ngrams of higher orders (bigrams and trigrams) than are typically used in augmentative communication applications. Since the accuracy of ngram prediction methods is highly dependent upon their statistical reliability, the effect of training text size on performance was also investigated. Keystroke savings is used as the single measure of predictive performance.

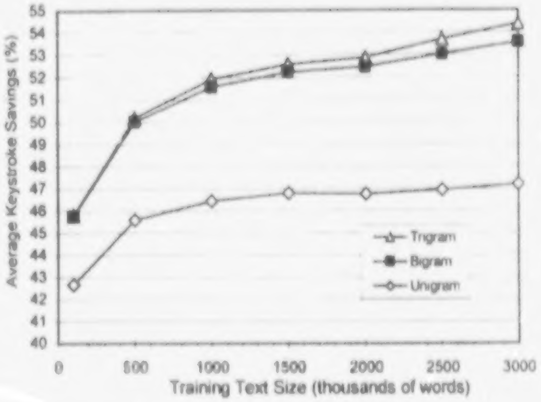

Figure 1: Keystroke savings as function of text size

METHOD

Training texts of sizes ranging from 100 thousand words to 3 million words were constructed by evenly combining text blocks from the Brown corpus, the LOB corpus, and a collection of Time Magazine articles. All headings and formatting directives were removed from the training texts. Comprehensive ngram statistics were automatically generated and stored for each training text. Twenty-one experimental conditions were established by combining three different ngram orders (unigram, bigram, and trigram) with each of the 7 training texts. For performance measurement, 7 representative testing texts of at least 2500 words each were employed. These texts, taken from a previous study of word prediction (3), varied widely in genre and linguistic sophistication. The content of the testing texts was independent from that of the training texts.

For each experimental condition, the 7 testing texts were independently generated using a 54 key QWERTY keyboard supplemented by a 10 word prediction list accessed using the F1 through F10 keys. Keystroke savings were computed for each testing text based on the numbers of keystrokes used to produce that text with and without prediction enabled. Keystroke savings were averaged across testing texts to provide a single performance measure for each condition. Because text selection was premeditated (rather than a random sample), inferential statistics were not applied. Automation of the entire text generation process made such extensive testing possible.

RESULTS

Figure 1 depicts the average keystroke savings for unigram, bigram, and trigram word prediction as a function of the number of words in the training text. For bigrams and trigrams, prediction components were interpolated to maximize accuracy (3). Performance increases with increasing training text size, irrespective of the ngram order. However, the increase is much more pronounced for trigrams (7.5 percentage points) than for unigrams (4.5 percentage points). For each ngram order, the shape of the performance curve is similar — a rapid increase followed by a gradual decline in the rate of improvement. Note, however, that even at a training text size of 3 million words, performance continues to improve at a non-trivial rate for higher order ngram prediction.

For a given training text size, keystroke savings also increase steadily with higher ngram orders. A large jump in keystroke savings is realized when moving from unigram to bigram word prediction (6.4 percentage points at 3 million words), reflecting the transformation from context-insensitivity to context-sensitivity. The performance gain in moving from bigram to trigram prediction is considerably less dramatic (0.8 percentage points), although the difference grows for larger training texts. Spot tests with higher order ngrams revealed an even smaller performance difference between trigram and quadgram (n=4) word prediction, although with larger training texts this difference may also increase.

DISCUSSION

Predictive performance can be improved by using higher-order ngram prediction techniques and larger training texts. Switching from unigram to trigram prediction increased keystroke savings by 7.1 percentage points (at 3 million words), while tripling the training text size from 1 million to 3 million words improved savings by nearly 2.5 percentage points (using trigram prediction). Performance could doubtless be enhanced using alternative methods, such as syntax-based prediction, but the simplicity of the proposed ngram methods make them particularly suitable for rapid incorporation into augmentative systems.

Although performance trends are similar across ngram orders, there are subtle differences which merit attention. For unigram prediction, performance has begun to asymptote at 3 million words — the system has learned nearly all it can about how frequently individual words appear. For bigram and trigram prediction, however, performance continues to improve at 3 million words — because there are so many linguistically valid two and three word sequences, the system has yet to derive meaningful statistics for most of them. These results imply that substantial gains may be realized by utilizing even larger training texts. Such a study is currently underway.

The cost of the performance improvement associated with ngram methods is reflected in the extended memory requirements for the resulting statistical databases. With today's inexpensive memory, however, the adoption of larger databases would seem warranted. Furthermore, preliminary research indicates that infrequent ngrams can be pruned from the database with minimal degradation in performance but sizeable reductions in storage requirements. Further studies are necessary to quantify exactly how these increases in predictive accuracy and keystroke savings will affect communication rates.

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A SYSTEM FOR AUTOMATIC ABBREVIATION EXPANSION

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ABSTRACT

A system for automatic abbreviation expansion was developed and tested for use with an AAC device. The system blends several technologies in a process that automatically expands user generated abbreviations while additionally providing spell-checking. Using a series of heuristic rules and a statistical language model, the system combines a series of rule scores and probabilities to rank valid word candidates in a list for user selection. Stressing flexibility, the system requires that users only follow two intuitive rules for the construction of abbreviations. Testing revealed that the system was able to correctly expand 91.9% of a set of collected abbreviations (using a 5 member list), reducing keystrokes by 14.8% when used in an experimental communication task.

BACKGROUND

Users of AAC devices have a common desire to increase communication rate over that possible with current systems. A simple and effective method for accelerating communication for AAC users is abbreviation expansion (1). Early systems utilized a lookup procedure, where codes were cross referenced with words or phrases stored in an abbreviation table. Although effective, this method requires the ongoing effort of memorizing new codes and maintaining an abbreviation table database. Demasco (2) improved upon this by developing a rule-based system that allowed natural abbreviations and unrestricted vocabulary access, eliminating the need to maintain a lookup table. This system is more flexible, but at the cost of reduced keystroke savings and some loss of generality. Additional functionality to separate misspellings or typing errors from abbreviation attempts is also important for an effective system. Mistyped or new words can mistakenly be interpreted as abbreviations and expanded into words unintended by the user. No currently available system provides a truly comprehensive approach to abbreviation expansion.

RESEARCH QUESTION

The main drawbacks of table lookup systems are the cognitive loads required to memorize — and later recall — the abbreviations stored in the table. Rule-based systems are inflexible and often require that the user apply unintuitive abbreviation rules when entering abbreviations. A truly comprehensive system must be flexible enough to handle a wide variety of inputs, process misspellings and typographical errors, and easily permit the addition of new words to the system lexicon — all while allowing the user to generate abbreviations naturally (2). Is there an intuitive abbreviation expansion system that can provide all of these capabilities?

STATEMENT OF THE PROBLEM

The challenge is to design a system that can accommodate the wide variety of abbreviation strategies used by different individuals. The system must provide users with the ability to generate abbreviations naturally within an interface that is both functional and effective. Keystroke savings is the primary goal, but the system must also manage other functional operations such as spell-checking, editing, and the addition of words to the system lexicon.

RATIONALE

This new design addresses the weaknesses of the current expansion methods by combining several new and existing technologies into a flexible and intuitive abbreviation expansion system that can provide significant keystroke savings.

DESIGN

The system requires that the user follow two intuitive rules for creating their own abbreviations: *i*) the abbreviation must start with the same letter as the intended word, and *ii*) the letters of the abbreviation must appear in the same order as they appear in the intended word (2). Both rules impose a minimal cognitive load, encouraging users to generate abbreviations naturally, saving keystrokes whenever possible.

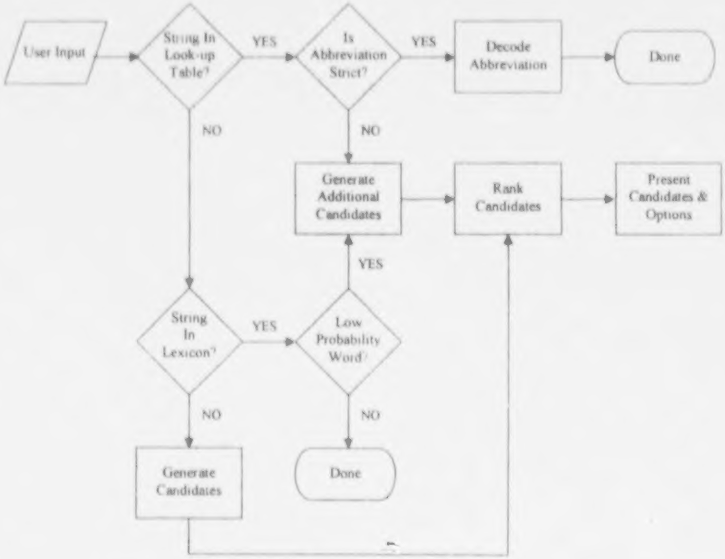

FIGURE 1: Flow chart of the expansion system

All input is first referenced against a standard lookup table of abbreviations. The system allows the specification of *strict* abbreviations in the lookup table. Similar to normal table entries, they force the system to exit the processing stream immediately. If necessary, the system continues processing after the table lookup and generates candidates which are ranked and ordered for presentation to the user. Candidates are generated for non-strict table entries and low probability words to correctly process misspellings that may result in a valid word (4). These unintended errors go undetected by current systems.

Candidates are derived from the system lexicon using the two abbreviation rules and a spelling checker (4). The ranking algorithm combines a heuristic rule score with probabilities obtained from the system's statistical language model to order candidates by likelihood. If none of the presented candidates is the intended word, the user can invoke a specific action, such as editing the input or adding the new word to the system dictionary. The system flow chart is shown in Figure 1.

DEVELOPMENT

The system was developed in software and integrated into an in-house AAC package for testing. Experimentally collected abbreviations were used to train the system and optimize the heuristic rule scoring algorithm and parameters of the ranking algorithm.

EVALUATION

The integrity of the design was evaluated with off-line testing and experiments involving a communication task. The offline testing was achieved by analyzing a database of abbreviation-word pairs (independent of the set used for training). Abbreviations were used as inputs to the system and the output was compared to the original word. The correct word appeared in a 5 member

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candidate list for 91.9% of the test abbreviations and ranked it as the top candidate 74.3% of the time.

The communication tasks were accomplished by enlisting experimental subjects to perform transcription tasks and answer questions using a device equipped with the expansion system. The software package had the ability to generate user log files recording the time and type of each selection as subjects used the device with and without the automatic expansion system engaged. On average, the users experienced a 14.8% keystroke savings using the system. However, the keystroke savings were achieved at the cost of an overall communication rate decrease of 30.8%.

DISCUSSION

The off-line performance demonstrated the potential of the system to properly expand abbreviations using a variety of natural strategies. When used within the AAC software package during a simulated communication task, the system provided a substantial keystroke reduction (14.8%). Despite the respectable keystroke savings, the 30.8% decrease in communication rate was unacceptable. The experimental data recorded during the communication tasks were examined manually in an attempt to identify why the subjects suffered such a rate decrease.

The session log files revealed that the subjects failed to experiment with the interface and exploit the features that would have saved additional keystrokes. Koester and Levine (3) have documented that the addition of word prediction lists (or other dynamic interface options) will increase the cognitive load on the user. Perhaps by fully utilizing the system's capabilities, the additional savings could have compensated for some of the increased cognitive requirements that accompanied the candidate list. Additional adjustments to the system interface and training procedure (to encourage full use of the system capabilities) are required if the system is to fulfill the potential suggested by the off-line performance and the measured keystroke savings. Subject comments suggest that this system can provide intuitive and effective abbreviation expansion. However, the decreased communication rate and sporadic use of abbreviations suggests that the real challenge may be educating users to leverage the full power of the system.

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ENGINEERING ADULT RESIDENCES FOR COMMUNICATION OPPORTUNITIES AND COMMUNICATION TRAINING

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ABSTRACT

In efforts to decrease the numbers of individuals living in state-operated facilities, state funding were allocated for the provision of assistive technology and services which increase the independent living skills of adults with developmental disabilities as they are transitioned to community living. To approach the augmentative communication needs of these individuals a muli-faceted plan was proposed for one facility. One component of that plan was the use of environmental communication boards within the adult programs and residences. The focus of this paper is the development of environmental communication displays for group homes and the strategies used to facilitate the use of these boards by direct care staff at to provide choice-making opportunities and communication symbol training.

BACKGROUND

In efforts to decrease the numbers of individuals living in state-operated facilities, state funding were allocated for the provision of assistive technology and services which increase the independent living skills of adults with developmental disabilities as they are transitioned to community living. The facility consisted for 30 group homes with 8-12 adults per household. It was estimated that approximately 75% of these adults had severe communication impairments and were unable to communicate effectively using speech.

To approach the augmentative communication needs of these communities a muli-faceted plan was proposed. The plan included the following:

- Add "communication dictionaries" to the annual speech-language assessment process of all individuals who are unable to communicate successfully through speech. The communication dictionaries are descriptions of the way each individual communicates, what methods they use to communicate and the meaning of specific gestures and behaviors. Share these dictionaries with all staff who interact with the individual.

- Modify the current communication training module for direct care staff. Add information about augmentative communication systems, communication dictionaries, behavior as communication, and strategies for maximizing communication with individuals who are unable to communicate through speech.

- Provide the facility's speech-language pathologists with direct training and learning opportunities to develop augmentative communication evaluation skills.

- Develop evaluation materials. Establish resources for borrowing equipment and building a loan library.

- Provide team evaluations of individuals to identify augmentative communication aids and strategies to meet their particular communication needs.

- Evaluate the communication needs and opportunities of the programs provided on each campus. Train program staff on strategies to facilitate communicative interactions and create communication boards to support those activities.

- Create environmental communication boards to facilitate communication within the residences.

ENGINEERING FOR COMMUNICATION

The focus of this paper is the development of environmental communication displays for group homes and the strategies used to facilitate the use of these boards by direct care staff to provide choice-making opportunities and communication symbol training.

OBJECTIVE:

To create communication opportunities and training integrated into the daily routine of adults with developmental disabilities.

METHOD OR APPROACH

Interview Staff To Identify The Vocabulary Needs For Each Home

Speech therapists went to the homes and explained that communication boards were being made for each home. Staff were shown samples of communication boards and told that these boards could be used to help them offer choices to residences. It was also explained that in situations when it was difficult to understand a resident, the boards might help them figure out what the person might be communicating. The direct care staff in each home were asked to identify the choices available to the residents in each of the following areas: leisure choices, household chores, television shows, snacks and places to go on grounds.

In addition, it was explained that some individuals might learn to be more independent in completing self care activities and chores if they had a pictured list of the steps for each task. For example, some adults need verbal prompts to brush their teeth, wash their hair, etc. If they had a list of these activities, they might not need the staff to stand over them reminding them what to do next. The staff were shown examples of picture sequences and were asked to identify the verbal prompts they provide during the following activities: toileting, moming care routine and evening care routine.

Create Choice Boards And Pictured Sequences With Directives For Staff

Utilizing the vocabulary generated by the direct care staff, eight individualized boards were made for each home. Most symbols were from Mayer Johnson's Boardmaker software. Some symbols were modified to be culturally sensitive and others were custom made using the Boardmaker software with a paint program. On top of each board, were simple directions on how to use the boards. On the choice boards, the sign said, "Point to pictures when offering choices". On the pictured sequences, the sign said, "Point pictures when giving directions". The following are samples of two boards created for one home (Figures 1 &2):

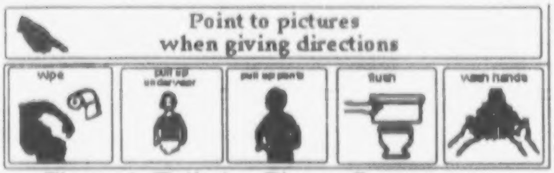

Figure 1: Toileting Picture Sequence

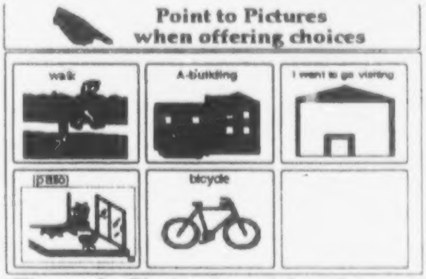

Figure 2: Choice board for places to go

Involve Staff In The Process Of Installing Choice Boards And Pictured Sequences

When the completed boards were brought to the homes, staff were again told the purpose of the boards and asked to verify that the vocabulary was correct. In some cases different staff where in the homes during the delivery phase than the evaluation phase. This provided opportunity for more staff to be trained. Staff were also asked for their input as to when each board should be mounted. Specific examples on how each board would be used was repeated as the board were put up through out the homes. All boards were laminated and mounted using contact paper. In general, choice boards for leisure activities and household chores were mounted in the common area, the television program choices were placed near each television set, snack boards were mounted on the door of snack cupboards or refrigerators and the choice board with places to go was mounted near the door. Toileting sequences were mounted over the toilet paper at eye level and daily care sequences were mounted in the area near the bathroom sink.

DISCUSSION

The creation and use of environmental boards is not a new concept. It is an approach broadly used with adults and children (Elder & Goosens', 1994) in educational and training environments. The turnover of staff in adult programs create a challenge to providing ways to keep staff informed and motivated to use communication displays. Further transition of programs to community living introduce new challenges. It was hypothesized that involving staff in the decision making process would increase support for implemented programs. In addition, it was believed that providing training within the home and giving examples specific their unique environment would be more effective than group inservices at general locations. Using this model, training was provided to staff in both the evaluation and implementation phases. During the implementation phase it was evident that many staff grasped the idea and purpose of choice boards and pictured sequences. Some independently identified other pictured sequences that they could use. Some staff identified specific people they wanted to use the boards with. In two homes, the staff began to use the boards immediately after they were mounted and the therapist was able to provide feedback while mounting the additional boards.

Systems need to be put in place to maintain use of the choice boards and pictured sequences through out staff turnover. It is hoped that the use of these boards by current staff will serve as models for future staff. It is also hope that the printed directions above the displays will serve as reminders as well as training aids for new staff. Information about the use of choice boards and pictured sequences needs to continue to be included in the training of new staff. It will also be important to provide periodic follow up visits to the home, to update vocabulary and respond to any problems as they arise.

It is hoped that as a result of this program, individuals will begin to use the communication displays in their environment to independently make request and clarify messages. This will be especially important for ambulatory individuals who do not carry communication aids or are unable to use communication displays that are outside their visual field. As these individuals transition to homes within the community, it is recommended that the home evaluations be completed as described above. Specifically, direct care staff in the homes should be interviewed to identify the vocabulary needs for each home, the boards should be custom made to reflect those needs and the boards should be mounted with input from the staff.

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THE GLIDER: AN ASSIST TO DIRECT SELECTION FOR AUGMENTATIVE COMMUNICATION

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ABSTRACT

This paper will present a new type of control enhancer, a glider mechanism, to assist an individual with athetoid cerebral palsy, in accessing his communication device. The glider provides a means of accessing an electronic communication device (specifically the Dynavox 2C) via direct selection when all other methods tried were unsuccessful.

BACKGROUND

There are two basic means of accessing a communication aid: direct selection or indirect selection. With direct selection a person is able to choose randomly from any items in a selection set on a display or keyboard. With indirect selection there is more than one step required in the process, a person uses a switch or switches and a type of scanning to access the device. Often direct selection is considered a faster means of accessing as the person makes direct contact with the key or message as opposed to waiting for the device to scan to the desired selection.

For Dominick, a 24 year old man, using his hand to directly select a message or key on an electronic communication aid was the method he hoped to achieve. Dominick had tried indirect selection methods but felt these methods were too slow to meet his needs. Dominick has athetoid cerebral palsy with quadriplegic involvement . He had been using a communication board with large squares (approximately 2" by 2") on his laptray. When attempting to access the desired messages on the communication board he needed to stabilize his hand on the tray in order to control the athetoid movements in his arm to successfully point to a square or message with his thumb. As the result of an augmentative communication evaluation, the Dynavox communication device was identified as the communication system which best met his needs.

STATEMENT OF PROBLEM

Accessing an electronic communication aid using direct selection became a problem for Dominick. Most communication aids do not allow for stabilizing the hand on the display to access a key or message. While Dominick could stabilize his hand on the top of the device (outside the communication display) he could only reach the first two rows of the messages. Using the device's built in acceptance delay did not work either as Dominick was unable to lift up his hand to activate only one key. With a keyguard his fingers either slipped into the keyguard spaces and accessed unwanted keys, or due to the athetoid movements his hand would hit on the keyguard and he would scrap his fingers. A control enhancer, such as a pointing device or mobile arm support was ineffective as he still needed a place to stabilize his hand to control the athetoid movements when pointing.

RATIONALE

In order to meet the client's desire for direct selection as an accessing method of an electronic communication aid, he would need a new type of control enhancer which would allow him to stabilize his hand and fingers yet free his thumb for pointing.

DESIGN

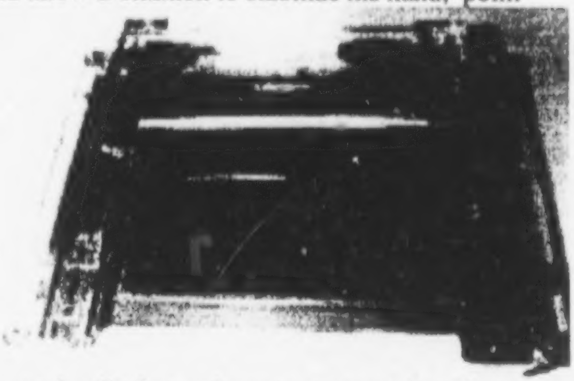
From the evaluation the following design criteria was determined. It would need to:

- Allow for stabilization of the hand and four fingers.
- Allow for the thumb to reach to all areas of the selection display on a Dynavox.

GLIDER

- Provide visual access to the display at all times.
- Attach to a Dynavox communication system.

A type of movable shelf (later termed glider) which would allow Dominick to stabilize his hand, point with his thumb and provide access to the entire display was needed. This lead to the design of a "glider" attachment to his Dynavox.



The "glider" is made of polycarbonate material and drawer slides. A clear polycarbonate shelf , approximately " wide and "long, attaches to modified drawer slides on either side. The drawer slides are bolted to a polycarbonate base which attaches (bolts) onto the Dynavox via four of the Dynavox keyguard clips.

RESULTS

With the glider, Dominick is able to stabilize his hand above the display and access a target size of 3/4" by 3/4" with the tip of his thumb. The shelf portion of the glider rises above the display approximately 1 inch. He pushes the shelf in two basic positions with his hand. The first position is at the glider's highest point to reach the top rows of the display and the second position is at the glider's lowest point to reach the bottom display rows. Dominick is able to move his hand horizontally along the polycarbonate shelf to access all areas of the display. With the glider attachment he is able to use direct selection as a method of accessing his electronic communication aid. He is also able to use a smaller display area than his communication board with access to more messages (using a device with dynamic display). With the shelf portion made of polycarbonate material Dominick is able to see through it to have visual access to the communication display at all times.

Dominick is now an active electronic augmentative communication aid user. He helps teach classes in augmentative communication and presents at conferences, often as an invited lecture. In his presentations he refers to himself as "just another Italian that speaks with his hand". Dominick plans to begin a computer training program and he plans to use his communication device to access the computer.

DISCUSSION

The glider, a type of control enhancer, now provides another option for a person to use direct selection with their hands as a means of accessing an electronic communication aid. This glider was designed for the Dynavox communication aid but a working prototype to accommodate several electronic communication aids has been designed for evaluation purposes.

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GLIDER

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EYE MOVEMENT CONTROL UNIT

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ABSTRACT

This paper presents the use of the electro-oculogram (EOG) signals, which then are conditioned to trigger a speech synthesizer, multimedia, and environmental control units.

BACKGROUND

There are bioelectric potentials generated in the body, which produce ionic currents. When we move our eye biopotentials are generated. These biopotential are called the EOG. As we look up, the upper areas of the eyes tend to be more positive than the bottom part of the eyes and vice-versa. The same is true for looking left or right. The most common electrode, silver silver chloride, can be used to act as a transducer, and an instrumentation amplifier can convert the ionic currents into electrical voltages so that electronic comparator instrumentation can be used to output digital controls.

STATEMENT OF THE PROBLEM

There are approximately 30,000 people that have cerebral palsy. Cerebral palsy is a disorder of movement and posture. Most people are usually paralyzed from the neck down. In these cases the people would rely on their eye movements to communicate with others. The client that this device is designed for also has cerebral palsy since birth. He has been looking up and down to correspond to yes and no answers. He is unable to speak, so we need to design a device, which will accommodate his needs in provide a way of communication and control of his environment.

DESIGN

The design approach consists of an EOG amplifier stage, TTL comparator, scanner, speech synthesizer with speakers, environmental control X10, and a T.V.-Stereo remote control. There is audio feedback to indicate the position of the scanner before it executes the command. Three electrodes would be place on the head, one on the forehead, one under the eyes on the cheek, and the third one behind the right ear for the grounding point. These three electrodes would be mounted on an eye glass frame. First the electrodes will convert the ionic currents into electronic currents. Then the EOG amplifier stage will amplify the difference in voltage between the two electrodes to many thousand times stronger, which will then be fed into a filter followed by a TTL comparator. The comparator will take this input and output a logic of 1 or 0 to activate the TTL decoder and scanning device similar to environment control scanners which are commercially available.

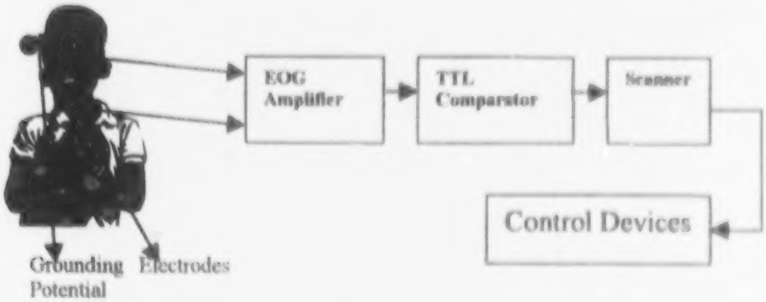

Figure 1. System Block Diagram

EVALUATION

Once the EOG amplifier stage was designed and constructed, we were able to record a reading of the EOG signals. The measurement result is shown in Figure 2. As the eyes move up and down, the voltage fluctuates up and down as well. The sharp drop where arrow is pointing represents the instant the eyes look down. The signal always measured to 400ms ±10% and not dependent on the voltage drop. This allowed for an active filter to be applied which cleaned the signal of none definite eye movement interference. All other signals after this point were eliminated with a bandpass filter. This downward slope can be used to edge trigger many applications. In our case, the signal will be used to trigger on a scanner with voice feedback.

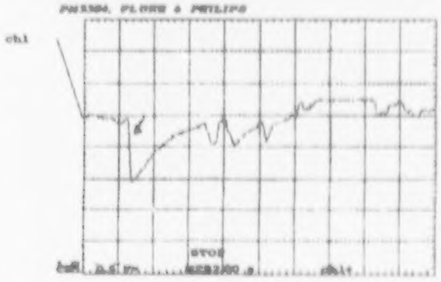

Figure 2: EOG Signal

DISCUSSION

There are biopotentials around the eyes that can be amplified and used in many different applications that allow control to a person with disabilities where no other control options are available. An example is our test client who has cerebral palsy and is unable to manipulate any of the standard control devices presently available. This EOG detection device with comparator and digital output was built with a component cost of under $130.00. Applications of this device for control expansion is only limited to the imagination and presents the return of control of environment and communication lost by physical disabilities.

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Computer Access and Use

SUPINE COMPUTER WORKSTATION: HOW TO LAY DOWN ON THE JOB AND NOT GET IN TROUBLE

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ABSTRACT

As computers become more and more prevalent in our daily activities, the computer workstation needs to become more adaptable to a greater number of users. For persons with mild to severe back pain, sitting at a desk using a keyboard for an eight hour work day may be unbearable. The ability to take pressure off the back while working is a necessity, but practically impossible using standard office equipment. The Supine Workstation was developed to alleviate this problem by providing a method for relieving back pressure while continuing to work at the computer.

BACKGROUND

The development of the Supine Workstation began when the design team was presented with a client employed as a computer securities specialist for a large corporate bank. This job required continuous computer usage throughout the workday. His office was equipped with a standard office chair, desk and computer with no special ergonomic considerations. He experienced extreme back pain while working and required frequent time off to recuperate from the day's work. The client has had two surgical fusion surgeries with orthopedic appliances in the L2-L5 region of the spinal column. The surgery addressed a degenerative disk disorder but he continues to experience chronic low back pain.

STATEMENT OF PROBLEM

The client was a respected and valuable employee of the bank, but sitting upright in his regular office chair applied too much pressure to his spine. As his pain became more intense, he was no longer able to work a full 40 hour work week. The only relief would come from laying on a bed or the floor for a few minutes to relieve the pressure. Due to the amount of recuperation he required, his weekly input had dropped to 30 hours. His employer was willing to accommodate him in any way possible, but could not find a viable solution to allow the client to continue working full time.

A thorough search for products to accommodate the client's needs was performed, with no positive results. Several products were found that addressed the need to change from a seated to a standing position. While this allowed for position change during the day, it didn't accommodate the need for the supine position required by the client.

APPROACH

After much consultation with the client about his pain relief strategies, it was decided that the ideal situation would allow for computer usage in the upright seated position and in a fully supine position. To accomplish this, the Supine Workstation was developed.

The Supine Workstation is designed around a BackSaver recliner. Changing the position of the recliner and attached Workstation requires no motor assist, as the recliner and workstation are fully counterbalanced. The device allows the user to recline from a fully upright seated position to a supine position, maintaining the relative position of the user and computer. See Figures 1 and 2. A 21" flatscreen monitor and an integrated trackpoint / keyboard rotate with the user on an axis

16.5/8" below the rotating axis of the chair. This offset axis provides the optimum arc for the computer components relative to the user. A 5/8" diameter stainless steel torsion spring mounted in the frame of the workstation provides the counterbalance for the weight of the monitor and keyboard. The flatscreen monitor was used for weight savings and to provide a large visual interface for the user.

Figure 1.

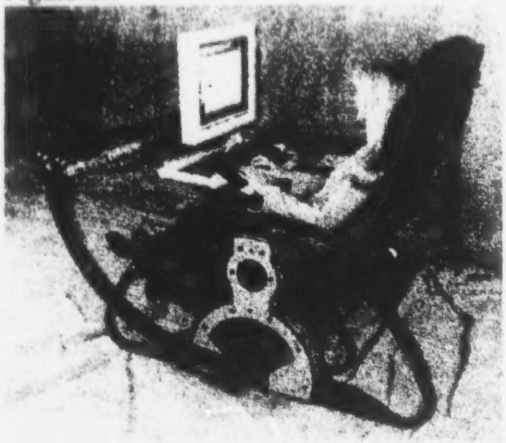
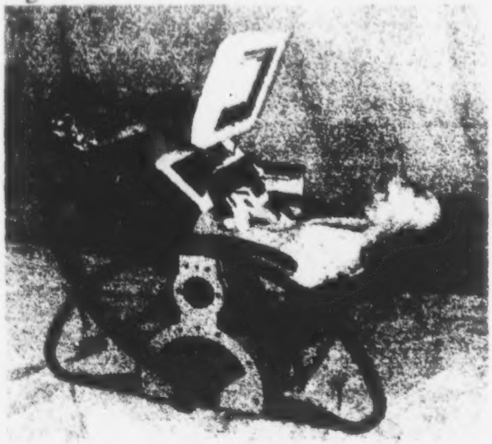


Figure 2.



To use the device, the client sits in the chair and pulls the roller bearing mounted monitor and keyboard tray over his lap. Independent adjustments are provided for the keyboard angle, height and depth as well as for monitor angle. See Figure 3. The monitor / keyboard unit may be rotated independently of the chair to provide the desired viewing distance for the monitor. These adjustments may be performed at any degree of chair recline. The computer, disk storage, and speakers are all located to the right of the user within easy reach. Additionally, a small writing surface is located above the CPU holder. See Figure 4.

Figure 3.

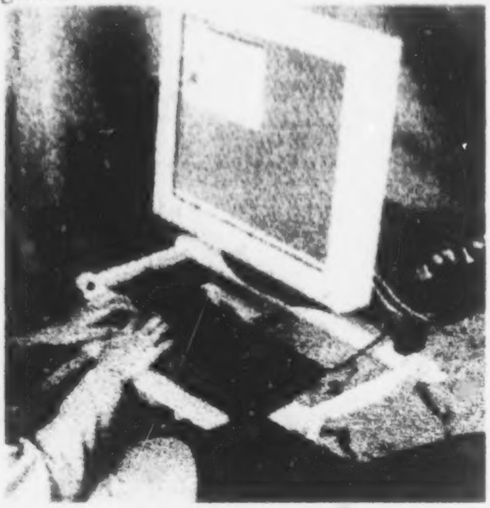
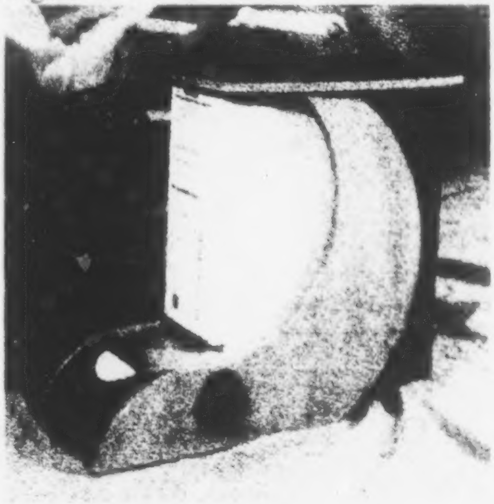


Figure 4.



EVALUATION

The client has been using the original device for two years in his home. After some minor adjustments to the mechanism, he has had no problems with the workstation. More importantly, he has returned to working a full 40 hour week.

Originally the mouse was not used by the client for input, as most of the work involved numerical input. After a short time, a mouse and mouse pad were attached to the keyboard tray. This proved problematic when the chair was tipped back to full supine. A new keyboard with integrated joystick mouse was installed and the mouse was removed. This solved the problem of the slipping mouse and lessened the movement required of the hand for using the mouse.

DISCUSSION

The Supine Workstation is installed in the client's home, as he telecommutes three days a week. On the other two days, he works at the bank headquarters for meetings and face to face interaction. To provide a low cost solution for his small office, a reclining office chair, adjustable keyboard mount and pivoting monitor stand were installed. This solution did not provide the amount of recline or flexibility he desired for pain relief, but is acceptable since his hours at the office are less than 12 hours per week.

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THE MISSING MODALITY: TACTILE MANIPULATION OF ELECTRONIC CURRICULUM

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Abstract

Presently, Internet or Intranet delivered curriculum does not simulate the experience of touching and manipulating objects or environments (referred to as haptics). This restricts the number of subjects that can be effectively taught, and the types of students who can access the curriculum. This paper describes a project that will develop software applications that make it possible to deliver curriculum that can be touched, manipulated and heard over the Internet or an Intranet. Both the necessary software tools and exemplary curriculum modules will be developed. Developments will be based upon the 3D ISO standard VRML, and a Haptic API developed by Haptics Technology Inc.

Statement of the Problem

Successful instruction of learners who are blind or students with learning disabilities, who favour tactile learning styles, is heavily dependent on touch and tactile manipulation of physical objects and models. Human beings begin life as multimodal learners. A child's natural instinct is to touch, manipulate, see, smell and even taste a new object. As the child matures, socialization favours some learning styles over others, but recent research has shown that many new concepts and skills are better integrated when more than one sense or modality is engaged in the learning process. No teacher would question the value of hands-on learning or practical demonstration. The result of our social bias toward the use of the auditory and visual channel has resulted in the well documented phenomenon of visual and auditory information overload (1).

For reasons of pedagogy, economics, access and efficiency, an exponentially increasing amount of post-secondary, secondary and elementary curriculum is being offered over the Internet, the World Wide Web, or an Intranet. With the transition to electronically delivered curriculum the modalities of touch and tactile manipulation are not presently available. From an access perspective, there are compelling reasons to add tactile manipulation and 3D audio to education delivered at a distance; luckily compelling reasons exist for all learners. Reasons to add haptic capabilities to electronically delivered curriculum include:

1. Some subjects, such as subjects involving sensorimotor skills or skilled manual tasks, are very difficult if not impossible to teach without hands-on experience
2. A large number of students learn optimally when their tactile sense is engaged and they are able to manually manipulate objects. This can be intensified for students with learning disabilities.
3. Students who are blind require tactile models that are flexible, scalable, and include dynamic linking to relevant information.

VRML

Virtual Reality Modeling Language (VRML) is a description language for three-dimensional objects, widely accepted as a 3D standard for transmission of 3D objects and environments over the

World Wide Web. Because of its relative compactness, VRML is the primary language used to transmit courseware involving 3D simulation over the Internet, the World Wide Web, or over an Intranet. Presently the VRML standard does not have provisions for haptic rendering or control, nor is it accessible to people with disabilities.

Haptic Technology

"Haptics" is a term that encompasses both the sensing and action involved in touching and manipulating. The primary reason the haptic modality is often the preferred mode of exploration is that it is the most active and interactive. Unlike the visual and auditory modality, by its very nature it is bidirectional and interactive. We manipulate the objects we are sensing in a continuous action-feedback-reaction loop. Thus many people do not feel they have really "seen" an object unless they have handled it and explored it using their haptic sense. Although VRML does not presently support the haptic modality, devices which display haptic information and allow haptic control are available. Haptic devices may be viewed as computer peripherals forming combined display/input devices. Where computer graphics addresses vision, "haptic" is concerned with touch and kinesthesia. Haptic devices make it possible for users to "touch," using their own hands and fingers, objects presented on computer displays as if they were real physical objects.

The Project

Extensions to VRML

Unfortunately, VMRL does not presently support haptics and physical models. Significant development efforts are required to add haptics and related modeling of solids to VRML. Preliminary studies conducted by Evan Wiess (3) show that three fundamental problems must be addressed in order to incorporate haptics in any VRML environment. First a method for specifying haptic properties must be developed. These include friction, damping, texture, vibration, etc. VRML does not provide a node for specifying these properties directly, however VRML does support a protonode which can be used to extend the VRML language. A multimodal protonode will be created that will include the specification of haptic properties. This node will also be used to group, position and orient multimodal information. Next a representation of the haptic device must be integrated into the VRML world. Finally, interaction between haptic devices and VRML objects must be specified.

Enhancements to the TouchKit

A generic, robust and modular software driver is required to display and control the extended VRML environments. This system should be device, system and application independent. This would allow different types of haptic devices to be connected to VRML applications, including 2D devices (such as the PenCAT) and 3D devices (such as the PHANToM). The system must also fulfill realtime requirements for haptic systems while using the real-time limitations imposed by VRML. TouchKit will act as the base technology for this software driver.

Courseware Authoring Tool for Educators

3D simulation courseware will not become popular unless there are tools which allow educators to easily create or modify this courseware. Existing tools are created for programmers with specialized 3D rendering skills. What is needed is a user interface shell which provides an easy to use front end to a collection of necessary utilities. This front end must use language and metaphors which are understood by the average educator and provide choices which the educator wishes to have available.

Model Courseware Application 1

The first exemplary courseware module will teach targeted curriculum in allied health education. Curriculum that involves anatomical visualization and teaches palpation will be selected. Targeted learning outcomes will be identified. The specific anatomical structure will be rendered using VRML, the VRML extensions and the enhanced Touchkit. In addition to traditional interactive exercises, the courseware module will include a monitoring or biofeedback capability that allows the student to objectively monitor their actions (e.g., the location and amount of pressure) and compare them to the ideal. The relative success of meeting the desired learning outcomes using the courseware will be determined through controlled user trials.

Model Courseware Application 2

The second module will provide geography curriculum to students who are blind. A full array of geographic structures will be mapped to haptic, auditory or combined modalities. Thus, students will be able to feel cities; from the associated tone which occurs when they encounter the city they will be able to determine the approximate size of the city. By pressing on the city they will hear the name. The student can choose to zoom into a specific location and query a large database of associated geographic data. If they want information on scale or relative location they can turn on a haptic grid which may feel like a number of strings or elastics strung over the map. Efficacy and usability will be determined through controlled user trials.

Summary

This project will add haptic and multimodal capabilities to the 3D standard, VRML. It will make VRML courseware accessible to students with disabilities, thereby providing a cost effective, flexible and powerful method of teaching spatially and graphically based curriculum to students who are blind or students who require tactile input in order to process new concepts. The project will also provide risk free learning environments for students learning manual skills such as physical therapy or skilled trades.

Acknowledgements

We would like to acknowledge the project team (http://www.utoronto.ca/atrc/rd/vrml/update.html) for their contribution, and Canarie Inc for its financial support.

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COMPUTER ACCESS CONSIDERATIONS FOR A PRIMARY-SCHOOL-AGE USER

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ABSTRACT

Margaret is a 10-year-old girl with severe limitations in upper-extremity strength and mobility as a result of spinal muscular atrophy type II. She is entering the 5th grade in a mainstream classroom. She wants to be able to use a computer to independently complete her assignments and participate in other computer activities. A wide variety of alternate input methods were considered. A combination of continuous speech-recognition and an onscreen keyboard were recommended. Special considerations for her age and school setting were made.

BACKGROUND

Margaret is a 10-year-old girl with a diagnosis of spinal muscular atrophy type II. She has no functional movement in her lower extremities. She is independently mobile in a power wheelchair with a joystick. She has bilateral elbow flexion contractures and limited upper extremity strength. She is unable to raise her shoulders against gravity or move her elbow when it is resting on her laptray (which she keeps on the chair at all times). During a spinal fusion operation one year ago, she suffered damage to the radial and medial nerves of her right forearm and hand. Consequently, she has decreased strength and movement in her right hand, and was forced to become left-handed. Independent feeding and writing were no longer possible.

When she was referred to a hospital-based assistive technology program for a computer access evaluation, Margaret was entering her first year in a mainstream middle school (fifth grade). During the previous year, she dictated most of her school assignments to her full-time aide. She had a computer at home as well as one available for her use in the classroom. However, typing was too slow and fatiguing to be functional. Due to her limitations in movement, she was unable to reach the entire keyboard with her fingers. In order to reach all of the keys, she used a pencil held in her hand as a typing stick. She was using a trackball for adequate mouse access. She was very active in using the computer for various academic and creative activities, but her aide actually operated the computer.

OBJECTIVE

Margaret, her father, and her aide felt that she should be more independent in completing her school assignments and in operating the computer for other activities at home. They were also concerned about the reliability of new aides in the middle school and the availability of computers in the middle school, where Margaret would be travelling from class to class. Therefore the objective was to provide her with an independent and efficient means for her to operate the computer at school and at home.

METHOD

After an initial interview was performed and goals were established, Margaret's current method of computer use was observed. It was immediately clear that this was inadequate. Since the priority was for Margaret to be able to complete homework and school assignments on her own, text-entry options were considered first.

Due to her limited range of motion, smaller keyboards seemed like an option. A brief trial with a Datalux compact keyboard revealed a slight increase in ability to reach the keys, but increased difficulty in depressing them. A TASH Mini Keyboard was tried, but Margaret lacked sufficient strength to activate the keys. Finally, a Magic Wand keyboard was considered, but was too small and sensitive for Margaret to accurately control (her ability to manipulate the Magic Wand stylus was limited by the weakness of her hands).

Since one of the limiting factors was her inability to move her elbow on her laptray surface, a bilateral forearm orthosis and a deltoid aid were tried. Although the BFO did improve her ability to raise her hand to her mouth for feeding (another goal of hers), the deltoid aid provided greater overall range and control. Margaret's lateral movement was greatly increased, but fine control was decreased. She also had continuing difficulty exerting adequate force to press the keys on a keyboard.

At this point, it was agreed that physical keyboards would be inadequate. The option of voice-input was discussed. Margaret had previous experience with Dragon Dictate but had found discrete speech recognition to be too awkward and slow. Although she was young for a speech-recognition system, she appeared to have a high level of maturity and had already demonstrated her aptitude for computers. We decided to consider continuous speech.

Initial trials with Dragon Naturally Speaking were completely unsuccessful. Margaret was unable to obtain any recognition during the first stage of training. Margaret's voice was highly intelligible, but was high-pitched and breathy and had a tendency to fade in volume at the end of each phrase. An attempt was made to bypass some of the initial stages of training by having someone else read the passages, but Naturally Speaking still refused to recognize any of Margaret's speech. Adjustments to the input-settings did not correct this problem. Research revealed that others had had similar problems in using this version (v2.0) of Dragon Naturally Speaking with children.

Another continuous speech-recognition program, IBM Via Voice 98, was tried. Initial recognition during training sessions was poor, but after many adjustments of the "speed" and "accuracy" settings, Via Voice 98 finally accepted Margaret's voice. Although the reading level of the training passages ("Treasure Island") was a little high for her, with someone reading the passages to her first, she was able to quickly and smoothly get through the training. Text-recognition was reasonable, although command recognition was poor until the "Computer please" prompt was enabled for all commands.

Speech-recognition with IBM Via Voice 98 now appeared to be a viable method for quick text input. Although using this system during class could be disruptive, since Margaret had already been dictating in-class assignments to her aide, it was decided that she could dictate to her computer during class as well. However, there will be times when dictating in class will not be appropriate - for example, during tests. An alternate text-input method was desired.

Margaret's control with a trackball was accurate, but rather slow. She tried a touch-pad and was able to use it with high accuracy and speed. With the touch-pad, she was able to operate an on-screen keyboard easily. Although this was not a fast input method, it was much faster and less fatiguing than her previous typing method on a keyboard. Margaret also quickly understood how to use word-prediction and abbreviation expansion.

The final recommendation was for a high-end laptop computer (to allow portability between classes and to home), IBM Via Voice 98, a touch-pad (built into the laptop), Wivik2 with the rate-enhancement package, and a Canon BJ-50 portable printer (to allow her to print in-class assignments). It was recommended that before she start using Via Voice in school, she should practice using it at home until she became proficient.

RESULTS

Margaret has now had her computer for two months. She immediately began using the touch-pad and the on-screen keyboard at home and at school. She is now using it to complete in-class assignments and to write letters and email. Due to a recent illness, she had not yet started practicing using Via Voice 98. She finds the computer useful in school, and one of her science teachers came up with a new way to incorporate Margaret's computer into class-work. During a chemistry experiment, Margaret was unable approach a lab counter close enough to read the measurements on a beaker that was sitting on a burner. Margaret's teacher used a digital still camera to take close-up pictures of the beaker during different stages of the experiment. She then put the pictures on Margaret's computer so that she could look at them and answer questions relating to those measurements.

DISCUSSION

Although Margaret is younger than most continuous speech-recognition users, several factors made her a good candidate. Margaret is an intelligent child who was already quite involved with computers. She also has an aide and a father who encourage her to use the computer and are computer-literate themselves. Although it may be some time before she is able to use speech-recognition functionally, by starting at such a young age, she will have the opportunity to become proficient by the time her academic program requires her to write more lengthy assignments.

To accommodate her academic setting, Margaret required input modes that could be adjusted to different situations that are likely to arise. Voice-input may be fine for general assignments, but for tests and other quiet times the on-screen keyboard with word prediction may be more appropriate. During spelling tests, the word prediction may need to be turned off. Since Margaret has an aide in school who actively encourages her to be as independent as possible, Margaret will receive the support she will need to make these constant changes.

Finally, Margaret's system will need to be adjusted as she gets older and her scholastic needs change. She may need greater support for math and science assignments; a method of taking notes; or more accommodations to increase her access to laboratory activities (such as the one her science teacher developed). Using her new computer access tools, Margaret will be well prepared to face these challenges.

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THE EFFECTIVENESS OF SPEECH RECOGNITION TECHNOLOGY

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ABSTRACT

Speech recognition technology (SRT) has the capacity to enhance opportunities available for persons with disabilities, yet very little research has been done to support its effectiveness. This study describes the effectiveness of SRT systems installed by one rehabilitation institute. Those surveyed included 28 persons who had disabilities. SRT was thought to be at least good or better by 75 percent of user subjects. While 67 percent of users found the two sessions of SRT training helpful, 75 percent of the subjects felt they needed more training. Fifty-one percent of the subjects type at 20 words per minute or greater (self reported). Paper handling was an issue for 46 percent of the subjects. There also appears to be a correlation between severity of disability and perception of the value of SRT.

BACKGROUND

Little research has focused on the effectiveness of voice recognition computer technology (SRT) for persons with disabilities. The research that has been conducted has generally found SRT to be helpful for persons with disabilities, but the results have been difficult to quantify or compare (Chamberlain, 1993; Goette, 1995; Day, 1995). Chamberlain (1993) found that 16 of 18 users of SRT said that it is "leading to a significant increase in the quality of their lives, and the remaining two said they thought it would". Chamberlain attempted to measure the effectiveness of speech recognition technology through a survey of several measures, including listing tasks SRT is used to complete, reporting the actual amount of time voice recognition technology is used, and rating the increased ability to produce written correspondence.

Goette (1995) identified several factors leading to the successful use of speech recognition technology including the user's perceived benefits of using voice recognition technology, and the user noticing results of using voice recognition technology. Goette also found that successful users used SRT for all of their computer tasks. Both Goette and Chamberlain used subjects with mobility impairments.

In a study examining SRT with another disability population, Day (1995) examined the effects of speech recognition on writing skills for community college students with learning disabilities. This study found that two of the three students studied wrote higher quality essays with speech recognition input than with traditional keyboard input. This suggests that SRT may assist some students with learning disabilities to improve written communication.

RESEARCH QUESTIONS

The objective of this paper is to describe user perceptions of SRT. Included in this description are: user perceptions of the SRT training they received, user reports of the amount of time they spend using SRT, and user reports of the challenges they have encountered in using SRT.

METHOD

The population identified for use in this study was all persons with disabilities who had received discrete word SRT systems from a University-based assessment center prior to June 30, 1997. SRT recipients generally received two full days of on-site training including an initial day of training and a follow-up training session. Of the 44 clients initially identified for use in this study, 28 chose to participate in the study. Disabilities identified included carpal tunnel syndrome, learning disabilities, multiple sclerosis, muscular dystrophy, quadriplegia, and other disabilities resulting in limited ability to use a keyboard for computer input.

Training

Training consisted of two sessions within a period of one month. In the introductory training session, the user's voice was trained and dictation and command and control skills were learned, drilled, and demonstrated. The session was completed when the user could successfully open a word processor, type text into a document, and print the document. The session time varied from approximately two to six hours at the user's home or office, depending on the user's ability and prior knowledge of computer. The users were then instructed to work through the chapters in the software manual independently. Telephone support was available during business hours. A follow up training session was scheduled within one month of the introduction session, based on the comfort level and readiness of the user. This session reviewed the skills from the first session, with shortcuts and advanced features demonstrated and practiced. This session ranged from two to six hours.

Survey

A 29-item telephone summary was developed, based on the previous research in this area, the professional opinion of the trainer, and the goals of this research. A four person pilot study was conducted to refine the survey. The survey consisted of multiple choice, yes/no, seven point scale and short answer. Some sample questions included "Did you have any computer experience prior to using speech recognition technology?", "How helpful was the training?", "Should the training be improved?" and "How would you rate your speech recognition system?.

These 28 subjects participated in a 29-item telephone survey designed to gather information about how they are currently using SRT, their opinions on the SRT training they received, and the problems they have encountered in using SRT.

RESULTS

More than half of the users (54%) had computer experience before using SRT. The two days of training was thought to be helpful or better by 67 percent of the subjects (In a range from "confusing, worse than no help at all" to " excellent, couldn't be better"). In addition, 61 percent of the SRT users thought the software manual was helpful or better and 21 percent thought it was somewhat helpful. However, 75 percent of the subjects felt that the initial training should be longer and 79 percent felt there should be more follow up training.

A self reported speed of 20 words per minute or better is achieved by 51 percent of the users and 18 percent were unsure at their speed. Non-SRT input methods are used by 61 percent of the users. These alternate methods included fingers, mouthsticks and splints. Paper handling of hard copy information was an issue for 46 percent of the users. Of those returning to school, 82 percent thought SRT was helpful. Overall, 75 percent of the users thought SRT rated good or better. Conversely, twenty-five percent didn't use the SRT system. Twenty-one percent of the users used SRT one to three times a week, while 54 percent used the system four or more times a week.

DISCUSSION

Additional training is clearly needed by users of SRT to maximize its potential. While most users thought SRT is good, training clearly needs to be improved. The training believes that the improvement desired is additional time. Two sessions of training is simply not enough time for a user to develop confidence using unfamiliar, sophisticated software. Providing training support in remote rural areas may be difficult, but it is essential. Perhaps a "train the trainers" model should be developed in various geographic areas. An aide or family member comfortable with computers could be present during the training to learn the system along with the user. Practitioners must address paper handling strategies and the user's goals. While not quantified, there was a strong inverse relationship between a user's level of satisfaction with SRT and the ability to use the computer without this accommodation. This probably accounts for the high percentage of those who do not use the system at all. With discrete word recognition, the threshold of benefit may not be crossed by some individuals who can use the traditional keyboard in some fashion. Continuous speech technology will likely lower this threshold.

This survey was a quick look at speech recognition. Additional research needs to be conducted with detailed statistical information, on the newer continuous speech recognition systems, the specific difficulties involving learning the software and importantly, the amount of training required to develop competence in SRT for computers users and computer novices.

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SOFTWARE FOR FUNCTIONAL ASSESSMENT OF COMPUTER ACCESS

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ABSTRACT

A Graphical User Interface Dexterity Evaluator (GUIDE) was developed for functional assessment of computer access capabilities. This software package provides standardized, quantitative measures of the user's skills in using a mouse or other computer pointing device. Exercises include selecting on-screen icons and tracking moving targets. Preliminary data was collected for a single subject with no movement disability. The software will be used to research alternative input devices for people with disabilities.

BACKGROUND

Functional assessment of computer access capabilities is necessary for a number of activities in the field of assistive technology. These include service delivery, product development, and research.

In the realm of service delivery, quantitative assessment can aid in the initial evaluation of a client's computer access abilities and in identifying limitations. A standardized assessment method provides a tool that can assist in comparing access methods, evaluating changes in the client's performance over time, and measuring the overall effectiveness of an intervention (1).

Standardized, quantitative assessment tools are also necessary in research. Research on human-computer interaction requires quantitative data on how people use computers. In order for this data to be compared between subjects and conditions, assessment tools must be standardized.

These tools are also useful in the development of computer access devices. By evaluating performance on prototypes, manufacturers can improve the usefulness of their final products.

STATEMENT OF THE PROBLEM

Functional assessment of computer access capabilities is a valuable tool for assistive technology. One important computer access skill is the use of a pointing device, such as a mouse or mouse emulator (3). This paper presents the development of a software package for functional assessment of a person's ability to use a computer pointing device. The package has been developed for a research setting, but the exercises implemented also have clinical applications.

RATIONALE

The GUIDE software package has been developed to provide a standardized, quantitative method of measuring user performance for computer pointing tasks. GUIDE presents on-screen exercises and records data related to user performance. The software incorporates established methods for studying user performance with alternative input methods (2) and the impact of disabilities on use of computer pointing devices (3).

DESIGN

GUIDE includes two exercises: a tracking task and an icon acquisition task.

Tracking

In this task, an icon moves across the computer screen while the user attempts to follow it with the computer cursor. The target icon starts at the center of the screen, and can move in one of eight directions: upward and downward, left and right, and four diagonal patterns (Figure 1). When an icon reaches the end of its path, it disappears and the next target appears at the center of the screen.

Investigator-defined variables for this task include target size, target speed, and the number of repetitions of the trial. As the user moves the cursor to track the target icon, the cursor path is recorded. Analysis of the cursor path can provide a number of dependent variables, including:

Distance Traveled: The maximum distance traveled by the cursor while following the target. Since the target icon moves from the center to the edge of the screen, this variable indicates the portion of the screen that the user is able to access.

Cursor Deviation: The root mean square difference between the actual path taken by the cursor and the ideal straight-line path taken by the target icon.

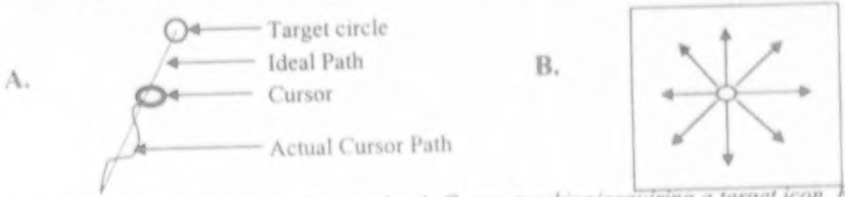

Figure 1: Tracking and icon acquisition tasks. A. Cursor tracking/acquiring a target icon. B. Eight possible movement patterns for tracking task; eight directions along which an icon may appear for icon acquisition task

Icon Acquisition

In this task, the subject attempts to use the cursor to select (acquire) icons that appear at various locations on the computer screen. The subject begins with the cursor at the center of the screen. A target symbol appears elsewhere on the screen and the subject moves the cursor to this target. When the target is successfully acquired, it disappears from the screen. If the subject is unable to reach the target after ten seconds, the target disappears and the computer records that the target was not acquired. Depending on the settings for the trial, either a new target will immediately appear or the subject must first return to the center of the screen. Returning to the center of the screen establishes a standard starting position for each target acquisition.

Icons are presented at eight directions from the center of the screen: upward, downward, left, right, and four diagonal directions (Figure 1). The investigator can choose to have icons appear at any of three distances from the center of the screen, and in either of two icon sizes; or in any combination of these three distances and two sizes. These icons can be acquired in one of two ways: by pressing a mouse button or switch, or by dwelling the cursor on the icon for 500 ms.

For this exercise, the software provides a number of dependent variables, including:

Movement Time: The time elapsed between when the target icon appears and when it is acquired by the subject.

Icon Acquisition: Whether the icon was acquired successfully.

Cursor Deviation: The root mean square difference between the actual cursor path and an ideal straight-line path from the center of the screen to the center of the target icon.

DEVELOPMENT

GUIDE has been developed for a Windows environment using Visual C++ v6.0 (Microsoft, Redmond, WA). Several data analysis routines were written for use with Matlab® mathematical software v5.2 (MathWorks, Natick, MA).

EVALUATION

In order to evaluate the GUIDE software, data was collected for a single subject with no movement disability. The subject performed six repeats of the tracking task and 30 repeats of the icon acquisition task with a standard mouse. The subject then performed six repeats of the tracking task and 30 repeats of the icon acquisition task with a HeadMaster™ head control system (Prentke Romich, Wooster, OH). Each repeat of the tracking task included all eight movement patterns. Each repeat of the icon acquisition task included 24 icons (3 target distances x 1 icon size x 8 directions).

Table 1: Results of evaluation trials. All significant differences are at the p=0.01 level

	Cursor Deviation (icon acquisition) Mean (Std Dev)	Movement Time (icon acquisition) Mean (Std Dev)	Cursor Deviation (tracking) Mean (Std Dev)
Standard mouse	9.59 pixels (6.17)	0.471 sec. (0.197)	8.37 pixels (5.76)
HeadMaster	14.60 pixels (14.7)	1.259 sec. (0.613)	19.0 pixels (12.1)
Significant difference	Yes	Yes	Yes

Results from this evaluation are shown in Table 1. Using head controls, the subject was not able to follow the moving target as accurately (larger cursor deviation for the tracking task) or acquire stationary targets as quickly (longer movement times for icon acquisition). The subject also had a larger cursor deviation for icon acquisition. These results are not surprising, since the subject was experienced in the use of a mouse and a novice at using head controls. However, these results are illustrative of the information that can be provided by the software. Figure 2 shows the cursor paths for two presentations of the same target in the tracking task. This serves to illustrate cursor deviation (7.12 for the top graph, 22.91 for the bottom graph) and distance traveled (96.1% for the top graph, 89.1% for the bottom graph).

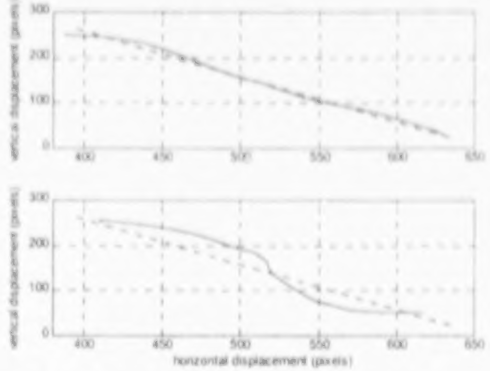

Figure 2. Cursor path for two repeats of one tracking pattern. Dotted (diagonal) lines are the ideal straight-line paths from center of screen to center of target. Solid lines are actual cursor paths. The top path was produced using the mouse, the bottom path using the HeadMaster.

DISCUSSION

In the future, the software will be used in research related to the use of a force-sensing joystick and the use of head controls for computer access by people with disabilities. Further exercises may be added to the software to test practical skills such as utilizing scroll boxes and onscreen menus.

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MORSE CODE LEARNING DEVICE

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ABSTRACT

Switches are often used by people with severe physical disabilities as the primary input device for assistive technology such as personal computers. When this is the case, Morse code can be used to allow the user to emulate keystrokes and mouse movements. The Morse Code Learning Device is designed to mimic the operation of Morse code software allowing one to learn Morse code before investing in expensive software and computer equipment.

BACKGROUND/STATEMENT OF THE PROBLEM

Commercially available Morse code hardware and software can allow individuals with physical disabilities to access computers using only switches. Morse Code hardware and software such as the Darci Institute's Darci Card and Darci Too[1], Don Johnston Discover Ke:nx[2], and Words+ ezKeys[3] are designed for this purpose. Many times, two switches are used. One switch represents a dash, and the other represents a dot.

Morse code is an input strategy that requires a certain level of proficiency to determine if it is a viable access method. In the past, the clinical team may schedule 1-3 training sessions using Morse code in the technology center. This was done to help the individual decide if Morse code was an option. This required additional visits for the user, additional staff time and still only gave the individual between one and six hours of practice.

RATIONALE

It would be beneficial to have a low-cost, device, that could be loaned to the user, that would give them more time to determine if learning Morse Code is right for them. Staff had tried providing individuals with switches and "switch testers," (devices that produce an audible sound when the switch is activated) in the hopes that this would be a tool that could be used by the individual to help learn Morse code. The drawback to this method is that to produce a code containing multiple dots or dashes, the users had to press and release the switch each time. Most experienced users of Morse code find that typing speeds can be increased, if the software can have the computer continue typing the dots or dashes for the duration that the switch is closed. For example, if the user wants to enter dot dot dot dot, he can press and hold the switch for a length of four dots. In other words, it is faster to close a switch for a count of four, than it is to open and close a switch four times.

DESIGN/DEVELOPMENT

To mimic the Morse Code software, this device must not simply beep when a switch is closed; it must be able to continually beep while the switch is closed. The Morse Code Learning Device does this by generating pulses as long as the switches are held closed.

The main component of the Learning Device is the 555 timer. It and the other components can be found at Radio Shack. The 555 timer is the integrated circuit that is used for generating the pulses. The pulses are then outputted to piezoelectric buzzers.

The parts list includes:

- (2) 555 timers
- (2) 10 k ohm resistors
- (2) 100 k variable resistors
- (2) 10 micro-farad capacitors
- (2) 3.3 micro-farad capacitors
- (2) piezoelectric buzzers of different tone frequencies
- (1) circuit board
- (1) 9 V battery

The circuit is basically two timer circuits side by side[4]. It also uses two different buzzers to produce the two different tones. The low pitch is for the dot, and the high pitch is for the dash. A variable resistor is used to adjust the speed and length of the tones.

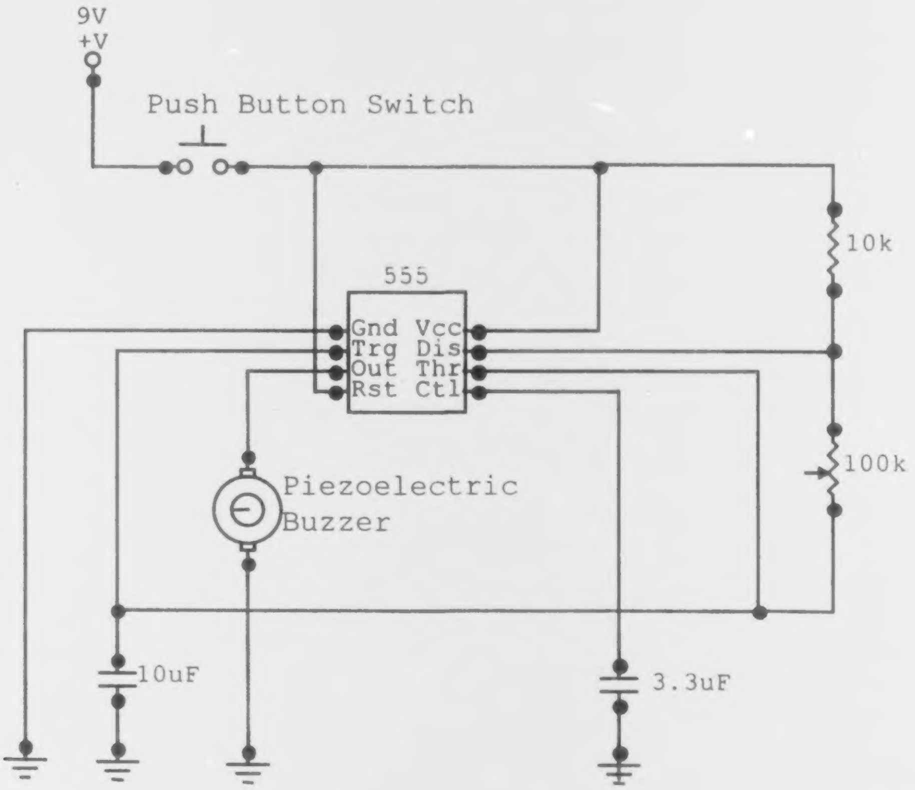
9V
+V
Push Button Switch
555
Gnd
Trg
Out
Rst
Vcc
Dis
Thr
Ctl
10k
100k
Piezoelectric
Buzzer
10uF
3.3uF

Figure 87

Figure 1 shows one-half of the total circuit. The second half is identical to this one, except the piezoelectric buzzer will sound a different tone. This circuit can easily be used with a sip and puff type switch.

EVALUATION

To date, the Morse Code Learning Device has been used with more than 15 individuals who reported that it helped them to practice and learn the codes. The majority of the individuals had the device for a single two week time period and upon return to the clinic, were able to enter text on a computer using Morse code, thus easing an anxiety they may have felt related to using Morse code as an input method. Additionally, several of the individuals reported that they did not believe that Morse code input was a viable option for them. Both of these scenarios were considered successful implementations of the Learning Device. Of the 15 individuals to use the Morse Code Learning Device, each reported that it was very useful in helping them make the decision whether or not to use Morse code as an input strategy.

DISCUSSION

One of the most useful and important devices for the disabled definitely is the switch. Morse code software has made the switch an even more effective tool for computer access. The purpose of this device is to allow the user to determine if they can learn Morse code before having to go to the expense of getting computer equipment. When the device has been used, it was recognized as instrumental in helping clients determine whether or not to use Morse code as an input method. Use of the Morse Code Learning Device gives switch users a head start in learning the code before a purchased Morse code system arrives. Additionally, use of such a device eliminated the need for subsequent evaluation training sessions in the clinic.

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ACKNOWLEDGEMENTS

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Environmental Adaptations, Modification, and Design

THE DESIGN OF DAILY LIVING AIDS FOR PEOPLE WITH RESTRICTED GROWTH IN COOPERATION WITH A SUPPORT GROUP

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ABSTRACT

It has been found that close cooperation with a support group is an effective method for defining and delivering aids for a specific disability group - in this case people with restricted growth. The Restricted Growth Association in the UK was able to provide volunteers for prototype evaluation; and a network of coordinators and a newsletter for information dissemination. Descriptions are given of eight aids that have been considered. A light weight step, two bicycles, two reaching sticks, toilet handles, portable car pedal extensions, and a children's bottom wiper.

BACKGROUND

PROJECT ORIGINS

The Restricted Growth Association (RGA) was approached as a group representing at least 700 members with restricted growth in the United Kingdom. Some of the memberships are whole families, so the actual number of people reached through the RGA is considerably larger than at first sight.

It was thought that working with a support group such as this would not only give ready access to volunteers for prototype evaluation, but also a straight forward means of promotion of the finished products via a member's newsletter. The RGA represents the majority of people with restricted growth in the United Kingdom.

A survey was carried out with members of the RGA to ascertain their unmet equipment needs. The survey used questionnaires and interviews, and led to a 'wish list' of the main priorities. This has been reported elsewhere(1).

DESIGN APPROACH

It is important that a new aid effectively satisfies the needs of the aid's intended users. To this end, the South West regional coordinators of the RGA were asked if they would be willing to help locate volunteers who would help compile a specification, evaluate prototypes and provide useful feedback about the evolving designs.

Design commenced in October 1996 with a visit to a family of volunteers to present the first projects to be designed and try and determine a first specification for each of them. Subsequent prototypes were evaluated by people with restricted growth for their ease of use and effectiveness.

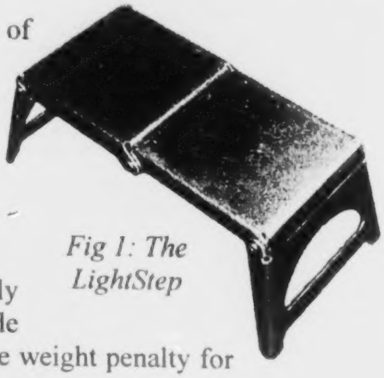

Fig 1: The LightStep

EQUIPMENT

LIGHTWEIGHT STEP

The LightStep is a lightweight folding step that can be easily packed into a shopping bag for example. The step will be made in two sizes. An adjustable height device was evaluated, but the weight penalty for the adjustability was not acceptable to users.

GENERAL PURPOSE REACHING STICKS

The initial survey showed there is a need for a stick for reaching doorbells, lifts buttons; and to assist with placing coat hangers on wardrobe rails. Consultation showed that there is a need for a device to use when shopping or when reaching objects from shelves in a domestic or work environment. These uses have been developed into two general purpose reaching aids - the ReachStick and the ShopStick.

ReachStick

The ReachStick is a lightweight, pocketsize reaching aid. It does not have a gripping tool, but is designed to be compact to carry and uncomplicated to use. It will accept a variety of tools, though the preferred option with the evaluators was a multipurpose prodder/hook design. The telescopic stick extends to 600mm and locks open at its maximum extension with a simple twist. It also locks closed. This device is also suitable for placing coat hangers on wardrobe rails.

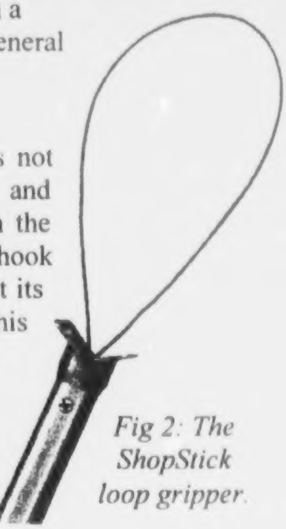

Fig 2: The ShopStick loop gripper.

ShopStick

This design for a stronger stick uses a gripping method that gives a secure grip on many different surfaces and materials. Folding into four sections, it extends and locks out to a length of 750mm. This has proved to be a useful length with our evaluators, without being so long as to be unwieldy. The gripper works like a noose, drawing a steel cable around the object to be picked up and then tightening around it against a ratchet. A button is pressed to release the object when it is in the desired position.

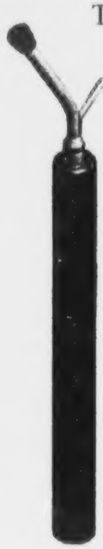

Fig 3: The ReachStick.

TEENAGE/ADULT AND CHILD'S BICYCLES

It was found that because growth restriction affects different people to different degrees, any bicycle frame must allow considerable adjustment if it is to be built in any number. It was found that biaxial adjustment is essential for the saddle and the handlebars, as arm and leg lengths are not necessarily in the same proportion to each other or the shoulder/hip measurement.

Commercial bicycle frames are designed for people of normal proportions. The limb shortening caused by growth restriction makes a conventional bicycle frame not only too large, but also of the wrong proportions. People with restricted growth are also prone to back pain, so an upright position is important. These factors result in an unconventional cycling posture.

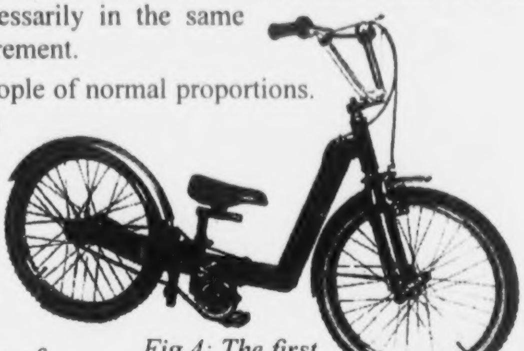

Fig 4: The first adult/teenage bicycle prototype

Another major consideration was the appearance of the bicycle. It is important to children and adults that the equipment they use is age appropriate. The bicycle was built in a 'BMX' style using standard components where possible. Some compromise on appearance was necessary to achieve the desired rider posture.

The brake levers, gear levers, and handlebars should be carefully selected so that they can be easily reached with the short fingers associated with achondroplasia. If possible, remove the need for one of the brake levers with a back-pedal hub brake. Evaluation of two prototypes showed the need for the option of back pedal or lever operated brake systems.

The transmission is conventional with the exception of its position and the short cranks used. The crank length of 43mm for the child's bicycle has made low gearing necessary (3:4) as the torque generated is much lower than with a conventional crank length - perhaps 100mm for children of this age.

Child's Bicycle

This bicycle is of a similar form to the adult design. It is suitable for children from about 2 years to six years. The design is simpler than the adult bicycle, there being no gears or a rear brake.

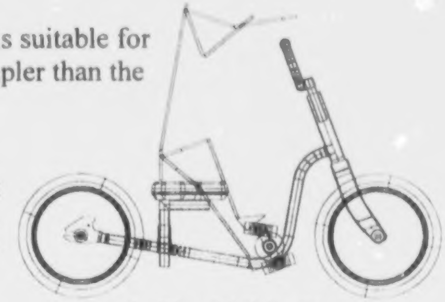

Fig 5: The Child's Bicycle, showing the posture of the rider.

PORTABLE CAR PEDAL EXTENSIONS

Many people with restricted growth drive cars. Most need their cars to be adapted so that they can reach the car pedals. Adaptation for restricted growth usually involves bolting extensions on the car pedals. If the car is shared with others in the family at work, then easily removable adaptations are required. Design of this device was not carried through as two suitable commercially available solutions were found to be suitable. Details were passed to the RGA.

TOILET SEAT HANDLES

Many people with restricted growth and particularly those with long bone growth restriction find that using a toilet is risky. Without legs long enough to reach the floor and arms long enough to stabilise themselves, falling into or off the toilet is a real possibility. A pair of handles that fit securely over the rim of the toilet without obstructing the lid and seat has been developed. During evaluation they have been found to be suitable for adults and children.

CHILDREN'S FOLDING BOTTOM WIPER

Having short arms means that many children with restricted growth are unable to clean themselves after using a toilet. A compact device that fits a child's hand can enable children to clean themselves and become independent of a carer's assistance. Figure 6 shows the wiper unfolded with its clip (left) open for paper to be wrapped around its end.

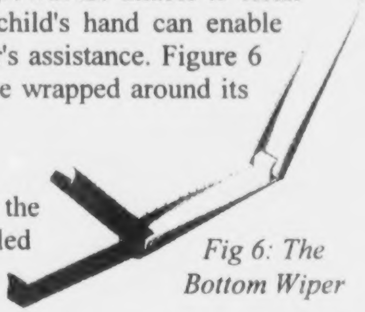

Fig 6: The Bottom Wiper

CONCLUSIONS

It has been found that working with an organisation such as the RGA is an effective way of defining and delivering aids to disabled people. Close cooperation with such a support group leads to valuable relationships with evaluating volunteers, ensures designs are truly effective, and provides a cost effective method of promoting and distributing aids to the people that need them.

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AGING AND PERFORMANCE CHANGES IN CEREBRAL PALSY

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ABSTRACT

The change in the performance levels over time of individuals with cerebral palsy was compared to a group without disabilities. The patterns of change were similar, but the effect on work status and attendant use was significant for persons with cerebral palsy.

BACKGROUND

The Available Motion Inventory (AMI) was developed with the objective of providing information about the environment that uniquely affects the manual performance of a specific individual with a disability (1). The AMI was developed over 20 years ago has been the basis for assessment of over 200 persons with cerebral palsy

A considerable body of knowledge is being developed about the aging process and approaches for maintaining maximal independence are being developed. Persons with cerebral palsy are also attaining greater longevity, but there is little known about what to expect regarding the changes in functional abilities that may be encountered.

The study "Uncertain Future: Aging and Cerebral Palsy-Clinical Concerns" by Turk, Overeynder, and Janicki (2) eloquently summarizes, "Adults with cerebral palsy age in the same way as adults in the general population. There may be differences, however, in the way in which the consequences of the aging process manifest themselves." Many persons with cerebral palsy experience significant changes in strength, dexterity, and endurance that are perceived as increasing their level of disability and occurring earlier than their non-disabled cohorts.

RESEARCH QUESTION

The objective of this study was to determine the effect of approximately 10 years of aging on the manual performance of a group of individuals with cerebral palsy. Did their pattern of performance change differ from a group of individuals without cerebral palsy? Was there a relationship between the amount and type of performance change and the level of independence or employment status of the individuals with cerebral palsy?

METHOD

A group of 30 individuals with cerebral palsy that had previously been assessed using the AMI were identified and information concerning the medical and work history of each was collected. Each was also administered the AMI again. A group of 10 persons without disabilities who were part of the original AMI norm group were also reassessed. The results of each subject's preferred hand were included in the analysis. The scoring of AMI performance is in units of standard deviations away from non-disabled dominant hand performance. That is, a score of 0.0 indicates a performance level equivalent to the mean of dominant hand performance of the norm group and a –2.0 indicates a performance two standard deviations below mean norm performance. This scoring system allows the averaging of scores across groups of tests.

RESULTS

Performance data was analyzed for a total of 32 subjects, 22 persons with cerebral palsy and 10 standards. Table 1 provides a description of the two groups. Scores were analyzed by the type of AMI sub-test. The sub-tests types were; switches (the time required to trip five different kinds of switches), settings (time required to make settings with three different input devices), rate (the rate of rotation for three different devices), force (pounds force exerted by fingers, hand, and arm in 10 modes), assembly (time required to perform nine simple assemblies), and reach-reaction (time required to react and move the hand to a target in four positions). The AMI performance of each group at their second testing is presented in Figures 1 and 2. Figure 1 indicates that the standards group performed at a level close to AMI norms (0.0) while the group with cerebral palsy demonstrated a significantly lower performance as was expected. Figure 2 presents the standard deviation of performance and indicates that there is much greater variability in performance within the group of individuals with cerebral palsy than the standards group.

Table 1. Demographics of subjects

		Cerebral Palsy	**Standards**
Number		22	10
Male		19	5
Female		3	5
Age at Second Test	**Mean**	39.8	43
	Std. Dev	7.6	11
	Min	30	28
	Max	61	64
Time Between Tests	**Mean**	11.4	15.8
	Std. Dev	2.9	1.8
	Min	5.7	13.3
	Max	17.1	17.4

The differences between AMI assessments over the test-retest interval are shown in Figures 3 and 4. The pattern of the change in performance over time of the two groups is quite similar as is shown in Figure 3 with Force and Assembly sub-tests showing the greatest decrease in performance and Switches and Reach showing the least for both groups. A t-test of significance indicated that only the reduction in Force was significant for the Standards group and Rate and Force were significant for the Cerebral Palsy group at $p<0.05$. The variability in the amount of performance change over time is illustrated in Figure 4. This indicates that the persons without disabilities had a greater degree of variability in the amount change experienced.

The relationships between AMI performance of the group of individuals with cerebral palsy. and the level of work activity and the hours of attendant use were examined, Table 2. The work

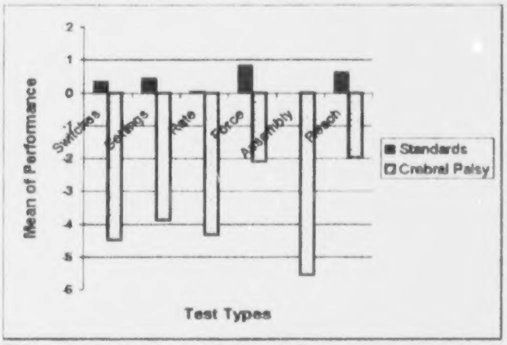

Figure 1. Mean AMI performance on retest

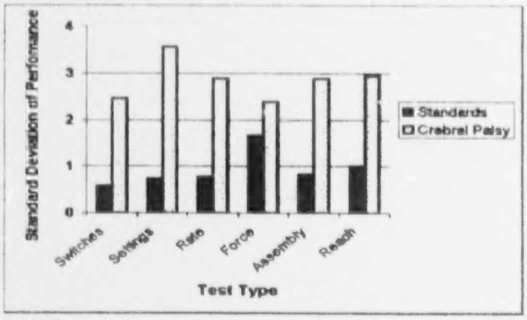

Figure 2. Standard deviation of each group's AMI performance

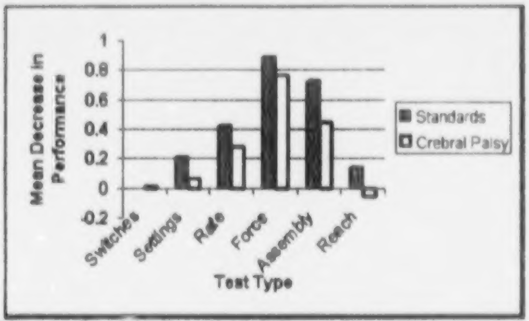

Figure 3. Change in AMI performance over time

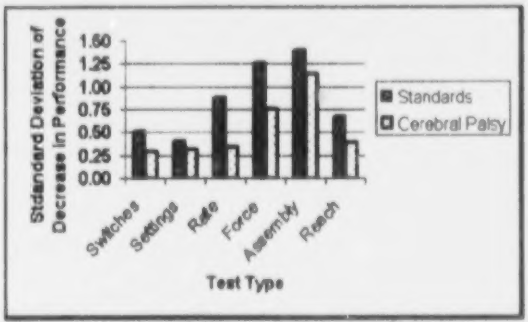

Figure 4. Variability AMI in performance change over time

level was scored in units of hours per week and weighted by the kind of work: volunteer, sheltered, or competitive. Attendant use was measured in hours per week. The results indicated that Force (or strength) and Assembly (or dexterity) were related to the current amount of attendant use and that a decrease in Assembly scores was related to an increase in attendant use

The amount of work currently being performed was related only to Force and a decrease in Reach (or hand speed) was related to a decrease in the level of work being performed

Table 2. Relationship between latest performance levels and changes in performance levels and the use of attendants and the level of work activity. (Significant at $p<0.10$)

Performance Tests	Latest Performance		Change in Performance	
	Attendant Use	Work Level	Change in Attendant Use	Change in Work Level
Rate	N.S	N.S.	N.S.	N.S.
Force	S	S	N.S.	N.S.
Assembly	S	N.S.	S	N.S.
Reach	N.S	N.S.	N.S.	S

DISCUSSION

The pattern of change in performance of persons with cerebral palsy appeared to be quite similar to persons without disabilities. They experience the same kinds of changes although over a smaller range. The impact of performance change over time had an effect on the level of independence experienced by the group with cerebral palsy. The pattern of attendant use and work experience were consistent with anecdotal evidence

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BEST COPY AVAILABLE

BREAD BAGGING DEVICE FOR USER WITH HEMIPARESIS: HEY, GET A LOAF OF THIS!

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ABSTRACT

Bakery workers must perform a multitude of tasks during the bread making and delivery process. Many of these tasks involve fine motor control, good dexterity and the use of two hands. For an employee who has hemiparesis, some of these tasks are impossible due to the two-handed nature of the tasks. A bread bagging device was created to allow such an individual to retain his employment and gain experience in the field.

BACKGROUND

The development of the Bread Bagger began when a local rehabilitation counselor regarding his client contacted the Center's design staff. A major grocery store chain employs the client in the bakery department. His job description includes such functions as bagging fresh bread, filling cream-filled pastries, customer service, clean up and operating the bread-slicing machine. The client has experienced a traumatic brain injury (TBI) resulting in hemiparesis on his right side.

STATEMENT OF PROBLEM

The client is able to perform many of the required tasks involved in his job, but was having great difficulty bagging the bread. This duty must be performed throughout the workday as soon as fresh bread comes from the ovens. Given that the bakery is at a major grocery store, this accounted for a large portion of his required work. There are five different bags, and up to seven different types of bread produced each day. Each type of bun, loaf or roll has a different sized bag and the bags have to be filled in an aesthetically pleasing arrangement. The client's primary duty is to arrange the bread, stuff the bread into the various bags and tie the bags closed.

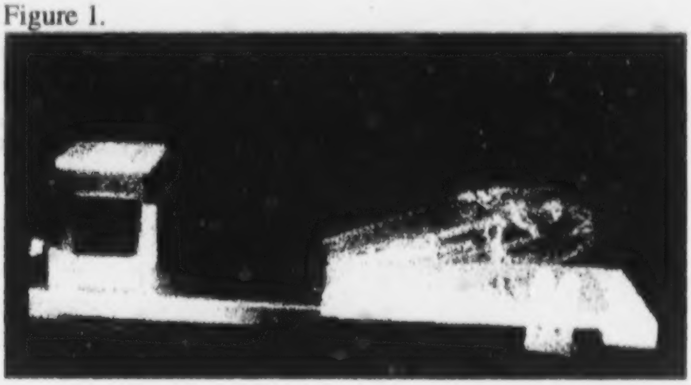
The traditional manner of filling the bags involves holding the bag open with one hand, while inserting the bread with the other. Many of the bags require the bread to be stacked or oriented correctly for efficient packing. Due to the client's ability to only use his left hand, this task was very difficult to perform in a timely fashion.

APPROACH

After consulting with the client, his employer, and counselor, it was agreed that the best approach would be to develop a device to aid in bagging the various types of bread. Since there are so many variables involved relating to the bags and types of bread, a universal device was needed which could work with any of the choices. The resultant device, dubbed the Bread Bagger, is a stainless steel platform with an attached fan, mounted to a nylon tray.

A miniature, 50 c.f.m. blower is mounted in a stainless steel housing 12" away from the bag loading area. The bags are placed in a stack on the nylon tray, utilizing the bags' peg holes as a mounting location. The peg holes are located on the leading edge of the bag, which extends beyond the actual lip of the bag. The hinged stainless steel platform is lowered onto the leading edge of the bags, clamping the stack of bags in place. When in use, the switch operated blower is turned on and proceeds to fill the bag with air. Once the bag is inflated, the client simply slides the bread into the bag. The blower will keep the bag inflated even as the bread is in the bag, allowing for stacking of bread. After the bag is filled with the appropriate bread, the client simply grabs the open end of the bag, lifts it off the platform and spins it with his fingers. After the end is twisted, he inserts the twist into a small V-shaped bracket mounted to the table (Figure1). He can then release the bag, and apply a twist tie to the end of the bag. The blower is usually left on, as he will have many trays of bread to bag at any given time.

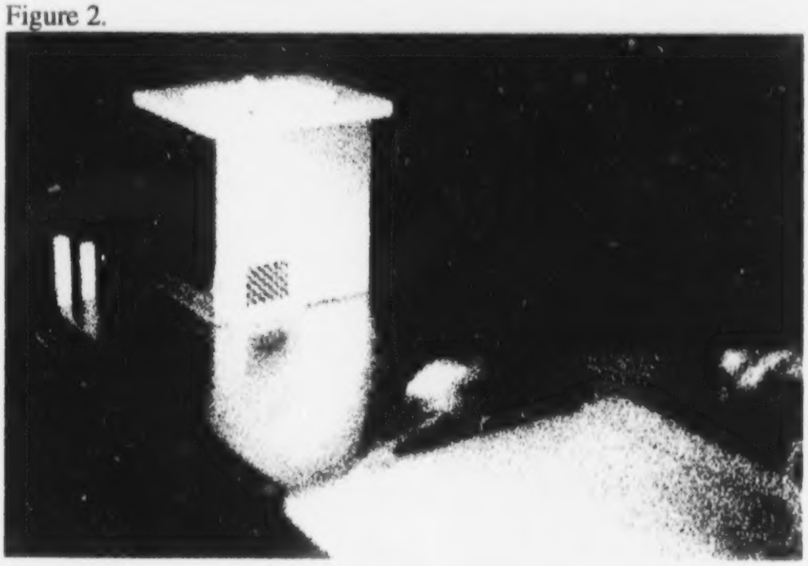
Figure 1.



When is a need for new bags, the stainless steel platform is tilted upwards, and new bags are placed on the pegs in the nylon tray. All of the different styles of bag have the same hole pattern in the top edge for ease of mounting.

All surfaces in the design are constructed of food-safe materials and designed to aid in clean-up. The stainless blower enclosure is fully sealed with silicon caulking. The blower opening is covered in a stainless steel mesh to prevent injury related to the spinning blower cage. (Figure 2.) The blower's intake and output screens are easily removable for the necessary cleaning. All surfaces may be cleaned in the same manner as the rest of the bakery, with no special consideration beyond keeping liquids from the electrical components.

Figure 2.



EVALUATION

The Bread Bagger has been in use for five months with no problems. The client's ability to perform his work is increased dramatically by the use of the device. The client was given training by the designer of the device as well as his job coach into the proper usage of the Bread Bagger. After installation, the client lifted the blower side off of the bakery table surface by inserting a 2-1/2" block underneath the device. This was done to create more of a gravity feed for certain rolls that could be stuffed without arrangement inside the bag. Because he is now more efficient performing this task, he can also expand his job duties by participating in other tasks at the bakery.

DISCUSSION

The client and his employer have been very pleased with the usefulness of the device. The employer is enthusiastically optimistic about the long-term goals of the client. If the client remains at the bakery for the long term, he will be given additional opportunity to try new tasks.

ACKNOWLEDGMENTS

The Center for Rehabilitation Technology Design Group would like to thank the client, his employer, Publix, and his job coach Mary Mullaney (Tommy Nobis Center) for their patience, input and cooperation in the creation of the Bread Bagger. Without the client's need and the funding provided by the State of Georgia Division of Rehabilitation Services this project would have never been realized.

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TOWARDS A GENERIC APPROACH FOR DESIGNING FOR ALL USERS

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ABSTRACT

It is known that many products are not accessible to large sections of the population. Designers instinctively design for able-bodied users and are either unaware of the needs of users with different capabilities, or do not know how to incorporate them effectively into the design cycle.

This aim of this paper is to present a summary of the principal methods for designing for users with different capabilities and to describe a model for displaying how the different approaches can be complementary and provide complete population coverage. The focus will be on design methods for the elderly, but it will be argued that age should not be a concern. The principal focus should be on physically capability, irrespective of cause.

BACKGROUND

Conventional product interfaces present serious difficulties to users with impaired motion, senses or cognition. Conditions exhibiting such impairments can occur throughout the life course, affecting all age groups, but certain symptoms, such as reduced hearing, appear with increasing frequency with advancing age.

There are two principal approaches to designing an interface for different user capabilities. The first is to design for a particular application and then tailor it retrospectively to different users. The second is to change the definition of the user at the very outset of the design process to include a wider range of capabilities. These approaches can be described as *adaptation* and *proactivity* respectively [1]. There is growing support for taking the second, more radical approach. It has been proposed that fundamental changes to the design philosophy are required to make interfaces more accessible and usable [2].

STATEMENT OF THE PROBLEM

A number of design approaches exist for users with impairments, irrespective of whether caused by aging or congenital conditions. Each approach has particular strengths and drawbacks for different sections of the population. The aim of this research is to develop an effective way of representing how particular approaches can be used to complement one another to provide the ability to design for the whole population.

APPROACH

The first step was to identify and review the common approaches to design for a wider range of end users. For example, *rehabilitation design* [3] focuses on developing specific solutions for specific problems. It has been claimed that the resultant products are not meeting the needs of elderly [4] or motion-impaired users [5] and this is reflected in poor sales figures [6].

Transgenerational design adopts the stance that products should be designed from the outset to avoid unnecessary accessibility problems on the grounds of age, by including users of all ages in the design process [7]. However, this puts the emphasis on age rather than capability.

Design by story-telling [3] adopts a four stage approach: (i) understand what it is like being old;

(ii) observe what old people do and how they cope; (iii) visualize a different scenario without technical constraint; (iv) evaluate a product for the full range of intended users. This approach again puts the emphasis on age, as if that is the source of difficulties, instead of appreciating that the only difficulties truly presented by advancing years is the increasing prevalence of impairments. Consequently, the method would be more widely applicable if 'impaired' was substituted for 'old'. Also, it is difficult, maybe even presumptuous, to try to *understand* what it is like being old. Understanding the *effects* of being old or, more correctly, being impaired, would be better.

Universal design [3] attempts to maximize the number of people for whom a product is accessible and usable. It achieves this by trying to make the user base as broad as possible. This is a laudable approach, although a key question that needs to be addressed is how inclusive 'universal' really is. Owing to the huge diversity of people and their capabilities, it is unlikely that a single product solution will be accessible by everyone.

The *user pyramid design approach* adopts a different philosophy. Here the user population is described as being in three broad bands. The able-bodied/fully capable make up the base of the pyramid, those with, say, reduced strength and mobility comprise the middle layer and the severely impaired occupy the peak. The approach claims that if products are designed to be accessible by severely impaired users, then the resultant product will be accessible by those with less severe or no impairments [8]. However the resultant designs may be sub-optimal for more capable users.

Building on the concept of the user pyramid with its banding of users by impairment level, a model was developed that relates capability level, population profile and suitable design approach in a simple graphical format. A representative version of the resultant model, referred to as the user cube, is shown in Figure 1. Each axis represents decreasing capability and the total volume is the complete population. The respective volumes enclosed by each approach reflects the total number of people catered for.

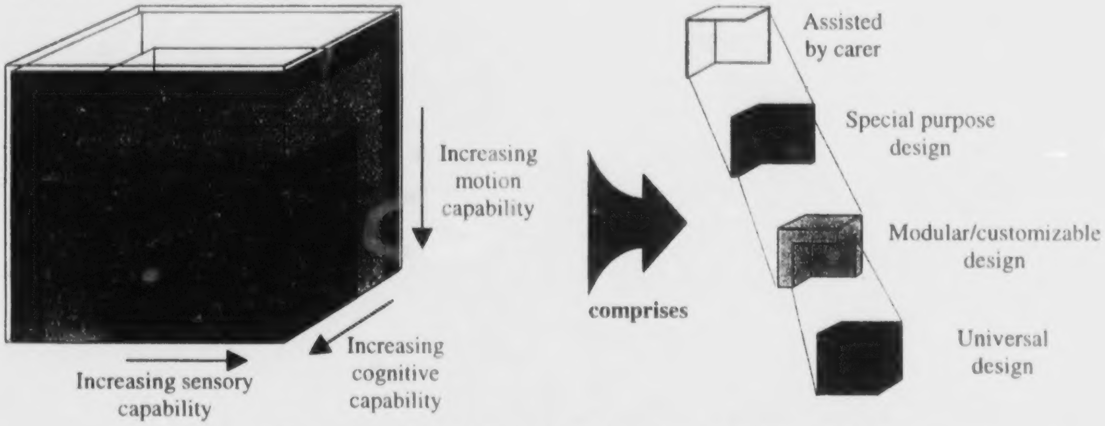
Increasing motion capability
Increasing sensory capability
Increasing cognitive capability
comprises
Assisted by carer
Special purpose design
Modular/customizable design
Universal design

Figure 1. The user cube - shown here for visual and motion impairments.

IMPLICATIONS

The user pyramid approach contends that there are three principal levels of capability: (i) severely impaired, (ii) moderately impaired and (iii) unimpaired. The user cube reflects this with three design approaches. It was recognized that the principles of universal design would generate products that would be widely accessible by large sections of the population and hence have good population coverage. Consequently this approach dominates the volume of the cube. However, it was also noted that the resultant products would be unlikely to be accessible to the more severely impaired.

For the most severely impaired users, a modified version of the rehabilitation design approach, broadened to include as many users as possible, is probably the most suitable model. This is labeled special purpose design in Figure 1.

In between the two approaches is an intermediary design approach that has extremely flexible boundaries. Modular or customizable design takes a base unit designed using the universal design principles, but with a changeable interface that is either adaptable or can be swapped for one of a series of modular designs.

DISCUSSION

First and foremost, the user cube requires calibration and validation. It is anticipated that the shapes of the boundaries will be dependent upon the nature of the task being considered and case studies are being prepared to verify this.

Once the cube has been calibrated, it will offer the designer a simple way of determining which is the most suitable design approach to adopt for a particular part of the population and also give an indication of how many people will be able to use the final product. This information about the final size of the market and, hence the expected economic impact, is invaluable in helping persuade those responsible for commissioning the design to target the widest possible user base. There is still a perception that impaired users are only of niche interest and this model is intended to help disprove that naïve attitude.

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THE DEVELOPMENT OF UNIVERSAL DESIGN PERFORMANCE MEASURES

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ABSTRACT

The authors are developing a set of universal design performance measures that reflect the Principles of Universal Design. The performance measures are intended to be useful for evaluating the broad usability of current products or product designs under development. The measures would be usable by consumers making purchasing decisions or by product designers in their design activities.

BACKGROUND

The authors are conducting a three-year field-initiated project, funded by the National Institute on Disability and Rehabilitation Research (NIDRR), titled "Promoting the Practice of Universal Design." The purpose of the project is to increase the acceptance and adoption of the universal design approach by mainstream product industries. The first project task is to develop a method of evaluating products to determine their universal usability; the second task is to develop an evaluation service for industry based on this evaluation method; and the third task is to explore the possibility of establishing a recognition or certification program based on the evaluation results.

STATEMENT OF THE PROBLEM

This paper discusses the primary goal of the first year of project work, the development of a set of universal design performance measures. These performance measures would be used to evaluate products that either currently exist or are under development. They would be employed by product designers to help guide their design processes and by consumers to help assess the universal usability of products they are considering purchasing. It is hoped that a single document can serve both purposes so that all audiences evaluate products against identical criteria.

RATIONALE

While great strides have been made in legislation to improve public access for individuals with disabilities, very little has been done in the area of products or environments intended for private use. However, the design details of personal devices and residential spaces can make a significant difference in an individual's ability to live independently and comfortably. To maximize the usability of these designs, advocates must influence industry to address the needs of a diversity of users. Rather than accomplish this through legislation, it is more effective and appropriate to provide manufacturers with market incentives to practice universal design. Researchers must demonstrate to companies that there are financial advantages to maximizing the usability of their products for the largest possible target market. In addition, they must facilitate designers' practice of the universal design approach.

DESIGN

In 1995-1997, the Center for Universal Design at NC State University coordinated the development of the Principles of Universal Design (1) (2) that describe the scope and intent of the universal design approach. The universal design performance measures developed by the current project are intended to reflect these Principles and their associated guidelines; therefore, the Principles were used as the basis for most of the draft performance measures.

Project staff developed five draft versions of the performance measures, including a questionnaire, a flowchart and a checklist. For example, among the Principles of Universal Design, Principle 2 is *Flexibility In Use: The design accommodates a wide range of individual preferences and abilities.* The design guidelines associated with this principle are:

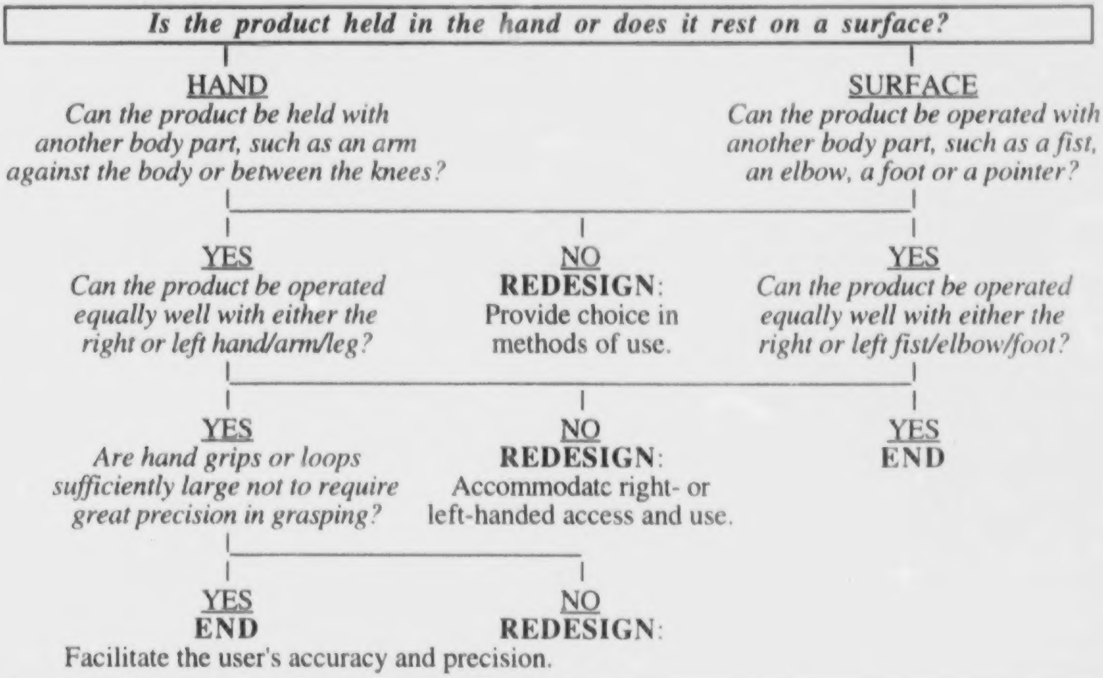
2a. *Provide choice in methods of use.*
2b. *Accommodate right- or left-handed access and use.*
2c. *Facilitate the user's accuracy and precision.*
2d. *Provide adaptability to the user's pace.*

In the draft performance measures, this principle was interpreted as shown below.

Questionnaire. The evaluator was asked to write responses to each of the following questions.

2a. *Describe various ways in which the design can be used (grip, orientation, etc.). Is each of these ways safe and effective?*
2b. *Can the design be used equally well by people with right or left-side dominance (right- or left-handed individuals, persons with hemiplegia, one side amputees, etc.)?*
2c. *Describe features of the design (such as push buttons or card insertion slots) that require accuracy or precision to use. Are these features easy to use accurately?*
2d. *Can the design be used safely and effectively either very slowly or very quickly?*

Flowchart. The evaluator was asked to follow the path to its conclusion. (Note: this represents only one section of the chart for Principle 2.)



Is the product held in the hand or does it rest on a surface?

HAND
Can the product be held with another body part, such as an arm against the body or between the knees?

SURFACE
Can the product be operated with another body part, such as a fist, an elbow, a foot or a pointer?

YES
Can the product be operated equally well with either the right or left hand/arm/leg?

NO
REDESIGN: Provide choice in methods of use.

YES
Can the product be operated equally well with either the right or left fist/elbow/foot?

YES
Are hand grips or loops sufficiently large not to require great precision in grasping?

NO
REDESIGN: Accommodate right- or left-handed access and use.

YES
END

YES
END

NO
REDESIGN: Facilitate the user's accuracy and precision.

Checklist. In this version, a departure from the Principles, the evaluator was asked to answer "YES" or "NO" to the following questions. (Note: this represents only one section of the total checklist.)

COGNITION: ***Is the design usable and safe if you...***

- *are using it for the first time without help or instructions?*
- *cannot read?*
- *perform steps out of order?*
- *try to use it much faster or slower than intended?*
- *make a mistake and want to correct it or start over?*
- *are distracted or interrupted while using it?*

DEVELOPMENT

The five versions of the draft universal design performance measures are being reviewed by more than 18 product design professionals and 12 product marketing specialists from across the United States, as well as 30 disabled consumers. Each of these constituencies is providing feedback on the format and content of the performance measures for their personal use. The draft measures are also being reviewed by a group of seven project consultants who are actively engaged in product evaluation or marketing programs, or who work with older adults or individuals with disabilities.

These reviews are intended to answer the following questions: Which format (e.g., questionnaire, flowchart, checklist) is most usable and effective for each constituency? …For all constituencies? What form should the answers to the questions take (e.g., yes or no, numeric score, comments)?

EVALUATION

Project staff will use the input from consumers, designers, marketers and expert consultants to develop a working draft of the universal design performance measures by the end of year one of the project, in May, 1999. In year two, the performance measures will be pilot tested by many of the same design and marketing professionals who took part in the initial review and by disabled consumers from across the United States. These individuals will apply the performance measures to evaluate six consumer products that are representative and important to independent living.

DISCUSSION

The authors believe there is a market for a universal design evaluation service for industry. This service would yield a wealth of information about the shortcomings of a given design and suggest ways to improve its usability by a diversity of individuals. This would benefit all consumers.

One concern of the authors is that as currently drafted, the performance measures assess only the usability of whole products.

- Is this sufficient, or would it be preferable to evaluate individual product features?
- Should the evaluation service also review the packaging around a product when it is purchased?
- What about product reliability and maintenance?
- What about other critical issues of product use, such as documentation and customer service?

Project staff realize that the third project task, the development of a recognition or certification program for universally usable products, is controversial.

- Would such a recognition program be valuable? If so, how should it be structured?
- If such a program is warranted, which organization might be best to administer it? Should this project ally itself with an existing organization such as Consumers Union or the ProMatura Group or would it be better to establish a new entity dedicated to administering the program?

The authors are seeking to resolve these and other issues in this project working to promote more widespread practice of universal design in mainstream industry.

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THE COMMERCIALIZATION OF THE REVERSIBLE TOILET/TRANSFER SEAT

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Kathleen O'Neill, New Products Manager, Maddak, Inc., Pequannock, NJ 07440

ABSTRACT

This paper is a case study on the development of a new product using assistive technology, and the consumer evaluation and the licensing of that technology by a manufacturer through AZtech, Inc., a company specializing in the commercialization of assistive technologies based on consumer input. The product is called the Reversible Toilet/Transfer Attachment and is available through Maddak, Inc., a manufacturer and marketer of aids for daily living. The original prototype submitted to AZtech was standard toilet seat with handgrips attached.

BACKGROUND

AZtech Inc, is a company that specializes in the commercialization of assistive technologies for the disabled and elderly usually by the process of technology evaluation and transfer. AZtech has evaluated hundreds of promising assistive technologies through their partner, the Center for Assistive Technology, University at Buffalo, New York under a federal grant program called the Rehabilitation Engineering and Research Center on Technology Evaluation and Transfer (RERC-TET). For those technologies or devices that show commercial potential, AZtech solicits companies for the possibility of manufacturing and selling a product encompassing the technology under a *license agreement*. This agreement gives the company the right to make and sell a technology (product) in return for a royalty payment that AZtech shares with the inventor or designer. [1] Twelve technologies have been licensed to manufacturers by AZtech over the past five years.

STATEMENT OF THE PROBLEM

Jim Bethanis developed a wooden toilet seat prototype with five handle grips surrounding the outside rim of the seat. Two grips were on either side of the seat and one was located in the front. Jim Bethanis has tremors as a result of Parkinson's disease. One place where his instability can be a real safety problem for Mr. Bethanis is in the bathroom. He found that while he had a grab bar near the toilet, he was pulled off balance by reaching for it. He designed the seat for himself and others who may have difficulties rising and/or sitting on a toilet seat. Mr. Bethanis received a U. S. Patent on the technology in 1998. After reviewing literature on AZtech and the RERC-TET, Mr. Bethanis decided to submit his prototype through the commercialization program. He needed help in finding a company to bring his device to market. AZtech accepted Mr. Bethanis' design and an *agent agreement* was executed granting AZtech the exclusive right to seek a commercialization partner for the design. AZtech would evaluate the prototype, research consumer opinions and develop a thorough commercialization report featuring the consumer's preferences for design. AZtech's goal was to present the device and report to interested manufacturers and ultimately transfer the technology through a license agreement to a manufacturer or *licensee*. The licensee's goal was to develop and market a finished product based on AZtech's recommendations and research. Once the product is on the market, AZtech would support the promotion and sales of the product to consumers and care providers so everyone can benefit from the new technology.

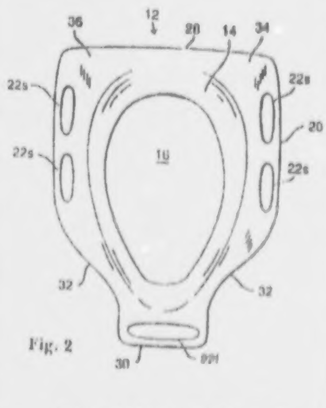


Fig. 2

Bethanis Patent Illustration

RATIONAL

Upon receipt of the prototype and design, a *device team* was formed with personnel consisting of marketing, consumer and technical professionals from AZtech and the Rehabilitation Engineering and Research Center. The team decided that the prototype and design of the toilet seat with handles could be shopped to potential licensees or manufacturers, but only with a recommendation on a redesign that would be included in the commercialization report or package accompanying the prototype. The recommendation on the design came from surveying potential end users or consumers of the device, a tool AZtech uses in their technology evaluations. AZtech gathers information on consumer reaction to concepts and inventions through the Independent Living Center of Western New York, (ILC), a third partner on the RERC-TET. Consumer focus group sessions were run through the ILC to gauge user reaction to the toilet seat with handgrips. The device was evaluated through a series of three focus groups with care providers and consumers. First the participants were asked to describe how they currently access the toilet and then they were asked for their recommendations on improvements to existing products. These discussions provide a valuable insight into the participants' options, usage pattern, attitude and buying process. [2] Second the participants were presented with the prototype and asked to enumerate on what they liked or disliked about the prototype and current products on the market. Finally the participants were asked how likely it would be that they would purchase a product like the toilet seat with handgrips.

DESIGN AND DEVELOPMENT

Results of the focus groups revealed that participants felt the prototype concept was worth while. However, they were critical of the design of the device. They indicated that the handle on the front of the device would be a nuisance and could even be dangerous. They also felt that the wooden prototype was heavy and they would prefer a single piece plastic design for aesthetic and sanitary reasons. The ideal toilet seat with handgrips would be lightweight and securely attached to the bowl and not slip during transfer.[3] Purchase intent was low for the toilet seat with handgrips in its original form.

The device team developed a commercialization report highlighting the results of the focus groups and the recommendations on redesign. AZtech solicited manufacturers with this information about the toilet seat with handgrips. A list of potential licensees was developed from in house manufacturer databases, manufacturer directories and trade show contacts. AZtech focused their company search on manufacturers of plastic toilet seats, riser seats and home health care bathroom accessories. The selected companies received a non-enabling description of the device along with a *confidentiality agreement*, which establishes non-use of the device without written consent from AZtech. Several manufacturers signed the confidentiality agreements and a commercialization report was sent for review. The report included the original design, the prototype, the status of its intellectual property, the consumer focus group results and AZtech's recommendation on design changes.

EVALUATION

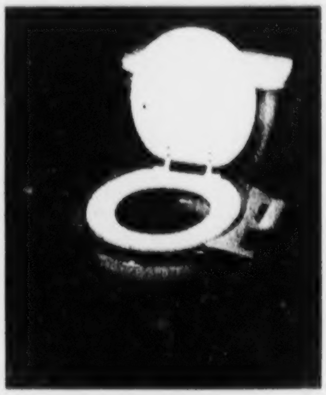
The new product concept intrigued Maddak, Inc., a major manufacturer of riser toilet seats. Their engineering and marketing staff reviewed the prototype and commercialization information sent by AZtech. The design team assigned to this project concurred with the focus group results that the additional handle in the front of the seat served no positive advantage and that a lightweight seat molded of plastic would be ideal for the necessary shape of the design. The members of the project team decided that since the commercialization report and consumer focus group results were favorable, then Maddak should look in to producing a product out of the prototype. A license agreement was executed between Maddak and AZtech. Maddak Inc. has rotational molding capabilities and decided the toilet seat with handgrips would be an ideal project because of its potential to be made using the same process. Therefore, the end product would be made out of lightweight plastic using this process, one of the recommendations from AZtech's report. The Maddak design team reviewed other suggestions from the commercialization report and held several design meetings in order to generate the final design of the device. Additional features were added to the design like armrests, and some were eliminated, like the front handle. Maddak believed they had designed exceptional product unlike any toilet seat transfer devices on the market

The product based on the final design is called a *Reversible Toilet Transfer Seat* attachment. One side of the seat provides a small-extended platform to help wheelchair users transfer onto the toilet seat. This platform can be used alone or in conjunction with other equipment that may be used during the wheelchair to toilet transfer. The gripping slots provide a secure and convenient place to grab the seat during transfer.

Alternatively, the other side of the seat has armrests that provide extra leverage for those people who have difficulty raising from or lowering to a standard toilet seat. This would be useful for individuals who do not require an elevated toilet seat or grab bars, but still need assistance due to arthritis, lower extremity weakness or poor balance. The one-piece construction assures that the armrests are permanently and securely affixed to the device. The added width between armrests makes this product useful for those who are overweight. The gripping slots located on each side of the seat may help to provide additional stability when seated or may aid in the contraction of abdominal muscles for those who are experiencing difficulty with bowel movements.

DISCUSSION

The Reversible Toilet Transfer Seat had a pre-market introduction at the HIDA (Health Industry Distributors Association) show in August 1998. The response was excellent and orders were received even though production had yet to begin. The formal introduction was at Medtrade 1998 and the response to the product was phenomenal. Buyers and therapists were excited that there was a non-elevated seat to help people who need extra assistance but who do not require an elevated seat. Maddak continues to review consumer oriented commercialization reports on technologies from AZtech for their next successful venture.



Reversible Toilet Transfer Seat
Maddak, Inc.

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CRITICAL FACTORS FOR EVALUATING AND COMMERCIALIZING INVENTIONS

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ABSTRACT

The Rehabilitation Engineering Research Center on Technology Evaluation and Transfer (RERC-TET) operated from 1993 to 1998. Its objectives were to identify prototype assistive devices, evaluate their potential value for consumers, and work to commercialize those with apparent value. The RERC-TET met its objectives by evaluating hundreds of prototype assistive devices, and transferring an average of five per year to manufacturers through licenses. This paper reviews the experiences, relevant findings and some of the critical factors of a successful technology evaluation and transfer program in the field of assistive technology.

BACKGROUND

The RERC-TET was funded by the National Institute on Disability and Rehabilitation Research, U.S. Department of Education. The RERC-TET was a partnership of three organizations, each representing a different perspective on the marketplace (1). The Center for Assistive Technology at the University at Buffalo performed the administrative functions of the grant, the initial screening of all contacts and the technical evaluations of submitted devices. Aztech, Inc., a not for profit community based enterprise run by and for persons with disabilities, was established by the RERC as the commercialization arm of the RERC. The third partner, the Western New York Independent Living Center or ILC, is a consumer advocacy group. The ILC Team brought the consumer focus to submitted devices (2).

The RERC-TET focused on implementing a supply push model of technology transfer. Within the supply push model, the RERC-TET solicited inventions of assistive devices, refined promising prototypes, and licensed them to manufacturers who transformed them into commercial products available in the marketplace.

APPROACH

The RERC-TET ran an exhaustive series of evaluations (3). The evaluations approved only new and unique inventions that demonstrated technical feasibility, market potential, and consumer acceptance. We then secured an agent agreement with the inventor. This allowed us to seek a commercial partner and form a product team comprised of members from our technical, marketing, and consumer groups.

The product team integrated all relevant device specific material into a commercialization package that was sent to prospective, previously identified, companies doing business in that device's specific market sector. These specific action steps and the RERC product team process are reported in greater detail elsewhere (4).

RESULTS

The large number of devices evaluated through this supply push program revealed critical factors which inventors, product developers, technology transfer agents, and companies could address to increase their success in transferring a new product into the marketplace.

Critical success factors for inventors:

a) Perform an extensive competing product search to verify that their product is unique and truly needed by individuals. One avenue to accomplish this is to seek out catalogs and companies manufacturing similar products through visiting DME dealers and contacting professional organizations. Other options include surfing the web for both similar products and patents. (e.g. *During the RERC-TET's existence, over 60% of the device submissions were rejected due to the existence of a competing product unbeknownst to the inventor.)*

b) Visit retailers and professionals to learn how individuals currently address that function or need through products currently in the market. Inventors should also seek out information about how those current products could be improved or in what areas they are deficient. It is not necessary to create a new product when improving an existing one meets the user needs. (e.g. *Wheelchair battery charging systems vary widely. Rather than inventing a new system, a company or inventor would best be served by improving existing systems already in the marketplace.)*

c) Contact prospective users of their device, seeking information about how they, the consumer, currently address the need the inventor's device addresses. Again, inventors should also seek out information about how current products used by the consumer may be improved or in what areas they are deficient and incorporate this information in their design. Inventors must recognize that consumers sometimes prefer a no-tech option because a device may not always be at hand. (e.g. *An old example of a no-tech option is consumers may prefer to dry their hair utilizing a towel rather than an electric hair dryer.)*

Critical success factors for product developers:

a) Partner with the appropriate stakeholders – manufacturers who have to produce a product at a profit and customers who make decisions to buy or use a product.

b) Seek out consumer input as to what features and qualities an invention may be lacking to make it a useful device that truly fulfills the needs of the consumers.

c) Be aware of and consider the manufacturing technologies that would be needed to mass produce a product, thereby choosing a method and material that would be most beneficial to a licensing manufacturing company. (e.g. *Exotic materials or processes should be avoided. Very few companies in the Assistive Technology field have the resources to invest in a new process for just one device in their product line.)*

Critical success factors for technology transfer agents:

a) Develop industry contacts and profiles so the agent can present their product to the right people, the right companies in a format acceptable to them. (e.g. *Possessing manufacturer profiles incorporating product lines, company policy, and correct contact information, is of paramount importance in being able to locate a company to license a product.)*

b) Develop a comprehensive commercialization packet for presenting critical information to prospective licensing companies. (e.g. *In most cases you will only have a few minutes of a corporate decision makers time for reviewing your material. It must be concise, possess needed information on marketing, technical and consumer issues and be formatted in a manner they can easily access and is familiar to them.)*

c) Educate inventors on reasonable expectations for royalties acceptable to companies licensing their device. Royalty rates of four to six percent are typical within our industry. (e.g. *In the RERC's existence we have had inventors receive and turn down lucrative, by industry standards, licensing and royalty offers in the hopes that they would get that "Pot of Gold" that they wanted. In fact their demands were excessive and* *unrealistic and they thereby missed the corporate "window of opportunity" to license their product. The corporation must go on to other products.)*

Critical success factors for companies:

a) Recognize inventors as opportunities to improve existing products and expand their product lines.
b) Listen to the end users when developing features of a product. Incorporate key consumer criteria in the design/sale/servicing of new products (5).
c) Accept and direct input from outside sources as a source of competitive advantage.

DISCUSSION

The most successful inventions, as common sensical as it may sound, are devices that fulfill a truly unmet need for at least a minimum segment of people and that address the critical factors mentioned previously. For inventors it is imperative for them to learn that their device is unique and to involve the end users of a device. Utilizing end user input in product development and in the marketing of a device will ensure a successful launch of a new and useful product.

For technology transfer agents it is necessary to possess the knowledge of which companies are seeking to introduce new products, and which corporations will not accept outside inventions. It is imperative that a commercialization packet that technology transfer agents will present to manufacturers contains a detailed consumer evaluation of the product, an extensive look at competing products in the marketplace and their device characteristics, a realistic and substantiated marketing/sales projection, and a technical evaluation of the device with suggested design changes. This, in effect, reduces the amount of effort and time a company has to expend in evaluating the device's new product potential. To optimize a company's return on investment, some new products must be brought to market quickly as they have a small entry window in the marketplace before they are surpassed by newer technology.

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OVERVIEW OF RERC ON TECHNOLOGY TRANSFER (1998 – 2003)

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ABSTRACT

The Rehabilitation Engineering Research Center on Technology Evaluation Transfer was established to facilitate and improve the technology transfer process within the field of assistive technology. It operates transfer programs to bring new inventions/technologies to the field (supply push), and identifies potential technology solutions to unmet needs (demand pull). The results of the activity are being documented through research, evaluation and dissemination programs.

BACKGROUND

The Tech Transfer RERC is designed to function as an intermediary and a catalyst, improving the technology transfer process while expanding the network of participants in the field of assistive technology. Accomplishing the mission requires close collaboration with academic, industrial, clinical, consumer and government stakeholders.

The Tech Transfer RERC is a partnership of four entities experienced in assistive technology evaluation, transfer and commercialization. the Center for Assistive Technology at the University at Buffalo, the Western New York Independent Living Center, AZtech Inc., and the Research Triangle Institute. The Tech Transfer RERC is funded from 1998 to 2003 by the National Institute on Disability and Rehabilitation Research.

OBJECTIVES

The Tech Transfer RERC has six Strategic Goals, each targeting specific objectives:

1. Improve the variety, quality and choice of products available in the marketplace through a Demand Pull model of technology transfer (i.e., identify product limitations, identify and validate technology solutions, then deliver them to industry). We expect to transfer up to three breakthrough technologies to industry per year to meet the objectives of device development and utilization.

2. Improve the variety, quality and choice of products available in the marketplace through a Supply Push model of technology transfer (i.e., identify innovative technologies and product prototypes, validate them by seeking product limitations and market opportunities, and deliver them to industry). We expect to transfer three to five new inventions to the marketplace per year, to meet the objectives of device development and utilization.

3. Evaluate internal and external models, methods and outcomes of technology transfer for continuous program improvement. Technology transfer occurs in dynamic environments and an intermediary requires feedback from all stakeholders. This activity meets the objectives of research and program evaluation.

4. Facilitate technology transfer by providing support and assistance on technical, marketing and end-user issues to RERC's and all other stakeholders. This will meet the objectives of training and technical assistance.

5. Document technology transfer program models, protocols and outcomes and disseminate to all stakeholders through appropriate forums and in accessible media, for dissemination purposes.

6. Establish strategic partnerships to accomplish the Mission, because it requires intensive cooperation and the commitment of each stakeholder group's management. This will meet the objective of collaborations with all stakeholder groups.

APPROACH

The Tech Transfer RERC has defined methods for accomplishing every objective. The dual objectives of device development and utilization will be met through the two approaches to technology transfer: supply push and demand pull technology transfer.

In the supply push approach, technology producers (e.g., inventors and researchers) push new technology developments toward the technology consumers (e.g., manufacturers and government agencies). This is called supply push, because the technology transfer process starts with an identified technology that is seeking an appropriate application.[1] In this approach, the technology or product supplied is pushed toward the marketplace with the expectation that it will meet a demand.

In the demand pull approach, product consumers (e.g., end-users and service providers) pull at product providers (e.g., manufacturers) to meet unmet needs.[2] This is called demand pull because the technology transfer process starts with an identified unmet market need which is seeking an appropriate solution—the identified demand is pulling a technology or a product toward it.[3]

Regardless of whether the approach is supply push or demand pull, a successful technology transfer will only occur if a manufacturer is willing and able to transform a technology in supply into a product in demand. The Tech Transfer RERC provides technical, market and end-user analysis to ensure that all of the stakeholders – particularly the private sector companies – are ready, willing and able to complete the transfer.

The Tech Transfer RERC is conducting one major demand pull project each year, focused on a particular assistive technology industry. The current project is assessing technology underlying wheelchairs and seating. The demand pull project involves five general steps. First experts profile the current technology limitations that result in functional limitations for devices or device users. Second, companies express their relative interest in overcoming the various limitations identified. Third, a forum involving all relevant stakeholders validates the importance and priority of the possible options. Fourth, the leading technology needs are translated into technical specifications, and circulated to all possible sources of new or improved technology solutions. Fifth, the responses are screened and offered to the private sector, along with appropriate technical assistance.

The Tech Transfer RERC's supply push program is similar to that operated by the RERC on Technology Evaluation and Transfer over the past five years.[4] The major difference is that instead of having an open call for inventions, the program now limits evaluations to devices submitted on referral from qualified sources. Submitted devices are reviewed for their technical, business and consumer merit. Devices with strong potential value to the marketplace receive our development and commercialization assistance. We are currently evaluating innovative devices in the areas of mobility, daily living, workplace ergonomics, and environmental control.

RESULTS

Both technology transfer programs have been underway since October 1, 1998. The most current summary of work in process and results achieved will be reported during the RESNA conference.

At that time, the demand pull project will have disseminated the technical specifications for key requirements to advance the state of practice underlying wheelchair and seating assistive devices. These will be available to the attendees. There may even be some progress to report on solutions offered in response. Also at that time, the supply push project will be able to report on progress in licensing innovative devices for manufacturing and distribution.

DISCUSSION

Functioning as a facilitator and a catalyst requires the Tech Transfer RERC to work in real time on the current needs of the private sector, particularly in those areas with a consensus on needs from the other stakeholders. By focusing the demand pull project on one industry each year, the RERC is identifying technologies ready for transfer in the short-term, and identifying areas requiring additional research and development in the long-term. By limiting the supply push project to a few devices with significant potential benefit to their producers and consumers, the RERC is focusing its resources to optimize the potential outcomes. The accompanying research, training, dissemination, technical assistance and evaluation programs, are all vehicles to share the experience gained through the actual process of transferring technologies to the assistive technology marketplace.

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MODIFICATION OF A CAMCORDER FOR A PERSON WITH CEREBRAL PALSY

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ABSTRACT

Jennifer, a 13-year-old, non-ambulatory young woman, wished to be able to videotape family, friends, and school activities. A video camcorder, with rotating 270 degree, three inch LCD screen, was mounted on and adapted to use on her powered wheelchair. The remote control unit was re-wired and connected to the two Environmental Control Outputs (ECU) located on Jennifer's wheelchair. This allowed the functions of the camcorder to be accessed through the use of her chin switch. This was done in order to avoid hard-wiring the camcorder directly. Jennifer was able to learn how to control the camcorder with just a little practice.

BACKGROUND

Jennifer, a thirteen-year old young woman, physically challenged with Cerebral Palsy, living in central Vermont, wanted to be able to independently use a camcorder. With no commercially available products on the market, Jennifer was unable to use the camcorder. Jennifer has many physical limitations, and has no functional use of her arms and legs. She needs assistance in getting in and out of her wheelchair. Her only means of access is through the use of her chin switch and scanner. This is currently how Jennifer operates her wheelchair and augmentative communication device. Jennifer does well with this set up. She also frequently uses this set-up to access her computer. Assessing her control unit, two ECU inputs were found available to be utilized.

METHOD

A JCV GR-AXM 700 LCD Compact VHS Camcorder was mounted on the wheelchair. The camcorder was interfaced with the one chin switch. The interface consisted of rewiring the internal parts from the camcorder's remote with two CD4016M / CD4016C Quad Bilateral Analog/Switch Multiplexer chips. The remote control had two commons; one with three outputs and the other with five. This caused a problem, due to the fact that the ECU is only capable of handling four inputs. Quad Bilateral Switch chips were chosen to alleviate this problem.

Originally, it was thought we would be able the run the wire straight from the remote control unit directly to the nine pin connector. We also had a problem with soldering the wires to the board, and turned to conductive glue. The problem with conductive glue was it took too long for the glue to dry, and the wires would move or break off the board. Finally, after exploring various other options, we turned back to soldering the wires and it worked. We began by soldering to the topside of the board later realizing we could solder to the bottom side of the remote and finished soldering there.

After that mishap, various control options were soldered to the two Quad Bilateral Switch chips, which in turn, were connected to two nine pin D-Subminiature connectors.

The limitation was four inputs per ECU, which were normally open contacts. This made eight overall inputs available. Each ECU has to be activated by the chin switch and scanner allowing only four choices at a time. Therefore, record, zoom-in, zoom-out and pause were grouped together. In addition, play, stop, fast-forward and rewind were grouped together.

The interface mechanism was housed in a plastic utility box (6 in. x 3 in. x 2 in.). The LED was removed from the remote control and attached to a cable. This cable ran to the front of the camcorder and connected to the plastic utility box via a phone jack. There is also an On/Off switch mounted to the side of the plastic utility box. This switch is used to power the interface mechanism with three volts D.C., which is powered with two AA batteries. This box is attached with Velcro to the top of the control unit in back of Jennifer's wheelchair.

Environmental Control Output Designations from Jennifer's wheelchair. – These connects are normally open relays.

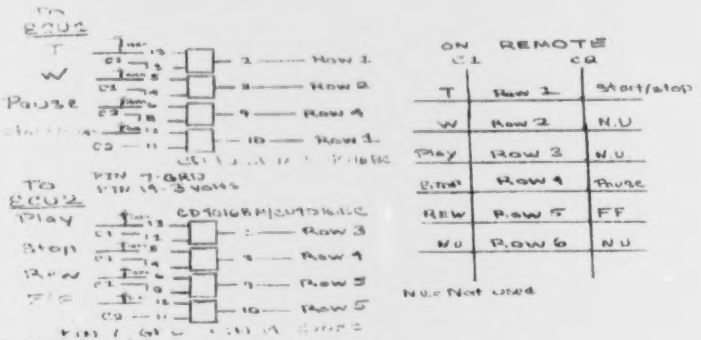
To
ECU1
T
W
Pause
Row 1
Row 2
Row 4
Row 1
PIN 7-GRD
PIN 14-3 volts
To
ECU2
Play
Stop
Rew
FF
CD4016BM|CD4016BC
Row 3
Row 4
Row 5
Row 5
ON REMOTE
C1
C2
T
Row 1
Start/stop
W
Row 2
N.U
Play
Row 3
N.U
Stop
Row 4
Pause
REW
Row 5
FF
NU
Row 6
NU
N.U.= Not used

Fig 1: Schematic

ECU One		ECU Two	
PIN	DESIGNATION	PIN	DESIGNATION
1	Zoom T (zoom in)	1	FF (Forward Fast)**
2	Zoom W (zoom out)	2	Rew (rewind)**
3	Start/Stop	3	Play*
4	Pause*	4	Stop*
8	Common	8	Common
5,6,7,9	N.C.	5,6,7,9	N.C
*Only VCR Mode		** Both VCR and Camera Mode	

In mounting the camcorder, one of Jennifer's old locking arms was used. The camcorder base attachment plate was an old triangular aluminum plate, from the locking arm, measuring 6 in x 6 in, which was milled into a triangular shape with two of the corners cut off. The piece now measured 6 in. x 4-¼ in. and was shaped somewhat like an arrow. Non-slip material, Dycem, was glued to the base plate to reduce shock and slipping of the camcorder. The camcorder was attached to the base plate by a ¼ in./20 knob screw. By placing the locking arm on the right side of Jennifer's wheelchair and making a few minor adjustments Jennifer was able to see the 3 in. LCD screen on the camcorder.

BEST COPY AVAILABLE

RESULTS AND BENEFIT

Jennifer was able to operate the camcorder with a little practice. It was easy to use due to the fact that the controls were the same as the ones used when driving her wheelchair and operating her augmentative communication device. The control pattern was setup in a simple way to make the controls easier to learn. All Jennifer had to learn was which button worked each control. The mounting system is easy to use and re-position. Presently she is using the camcorder to tape her class officer meetings. Jennifer is the secretary of her class.

DISCUSSION

This product works great for Jennifer's needs. The camcorder mounting system is easily adjusted. Since Jennifer already had the locking arm and GR-AXM 700 LCD VHS Camcorder (MSRP - $999.95), only a few parts costing about $30.00 and extra remote unit at $32.55 were required. Total cost to complete this project was a little less than $65.00.

This project took us five weeks to put together working about 20-30 hours per week. We had no previous knowledge of how any of the wheelchair parts or the how the camera worked and spent many hours learning about all the equipment. Once we had a clear understanding of how all the equipment worked, it took about a week to put together.

This camcorder set up works well for Jennifer, however the camcorder itself and the interface mechanism still have to be manually turned on/off as well as changing from video to VCR mode, which has to be done for Jennifer.

Not only was this a great learning experience, it also makes Jennifer happy. She now can do something that she was unable to do before.

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DESIGN FOR AUTOMATIC SYRINGE OPERATION

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Abstract

Syringe operations performed daily by a patient with paraplegia for urine extraction from and irrigation of a surgically created bladder operation resulted in carpal tunnel syndrome. In order to alleviate hand and wrist pains, two approaches were taken: adaptations to existing syringe operation and use of a electrical fluid pump. The DeVilbiss Vacu-Aide Portable Aspirator[1],used for tracheal extraction, was identified as the final solution. Given the frequent occurrence of carpal tunnel syndrome in scientific and hospital laboratories, further investigation on the application of automatic means to replace manual syringe operations seems warranted.

Background

This case study involves a client whose regular use of a syringe led to the development of carpal tunnel syndrome. The client was a 51 year-old female with L4-S1 incomplete paraplegia who had a surgically created alternative bladder called an Indiana pouch. Her diagnosis also included hiatal hernia with reflux, premature ventricular contractions, asthma, and peptic ulcer disease. In September of 1990 she experienced the onset of left lower extremity radicular pain with paresthesias. Subsequently, she underwent lumbar laminectomy at L4-5, however low back pain continued post-operatively. In addition, left sided foot drop and some urinary incontinence developed after the surgery. In 1991 another surgery was performed for a L4 to S1 fusion with L4-5 foraminotomy. After the second surgery, her urinary incontinence persisted and she was diagnosed with bladder dysfunction secondary to her back disease, or more specifically poor bladder sensation and detrusor instability with a coordinated sphincter.

In 1994 the client underwent surgical procedures for a continent Indiana pouch. The Indiana pouch was formed by sectioning off the ascending colon and ileum from the transverse colon and small intestine respectively. The colonic end of this isolated bowel was sutured closed, the ileal end of the segment was brought through the abdominal wall to a stoma, and the ureters from the kidneys attached to the pouch (Davidson et al., 1990).

The Indiana pouch had to be drained every four to six hours through self-catheterization. To alleviate the effects of mucus secretion from colon membrane, occasional irrigation was also required to maintain the viability of pouch. The catheterization methodology confounded discomfort in the client's wrist and hand that she had previously encountered and she was diagnosed with carpal tunnel syndrome. As a result, her case was referred to our program. A description of the process to find an alternative solution for urine extraction is presented.

Problem

Self-catheterization was a two-step process: (1) urine extraction and (2) pouch irrigation. Urine extraction consisted of inserting the catheter into the stoma, connecting the catheter to the syringe, and drawing urine from the Indiana pouch. For irrigation, saline solution was injected into the pouch via catheter and drained out of the pouch. Irrigation was repeated until mucus secretions were adequately thinned. Since the left and right hand stabilized the catheter and the syringe respectively, the right thumb was used to both pull and push the 200cc disposable syringe. As a consequence of daily catheterization, the client reported hand swelling and numbness in the median distribution of the hand, resulting in the carpal tunnel syndrome diagnosis in the summer of 1998.

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[1] DeVilbiss Vacu-Aide Portable Aspirator Med Equip 2850 S. Industrial Hwy., Suite 25 Ann Arbor, MI 48104

Objective

An alternative catheterization strategy that resolved the issues of high repetition and force while maintaining the integrity of the Indiana pouch was needed to prevent further aggravation of her carpal tunnel syndrome.

Method

As an attempt to define a simple and cost-effective solution to free the hands, the first approach taken was to construct a syringe holder mounted on an U-shaped base made from Kydex board. The syringe holder had lock-in mechanisms that secured the needle nozzle and the rim of the syringe. The U-shaped base was shaped around the client's right hip, which allowed the client's body weight to secure the syringe to the stoma. An adaptive handle for the push and pull of the syringe was connected to the dispenser.

After experimenting with the syringe holder, the client reported several complaints. First, the U-shaped base did not fit well when she assumed different body positions. Second, despite the redistribution of hand pressure from the adaptive handle, hand and wrist pains continued. Third, the size of the syringe holder created problems of aesthetics and traveling convenience. Although further modification were attempted to address these issues, the client did not find them satisfactory.

The second approach taken involved the use of fluid pumps for draining and irrigation. A variety of pumps (e.g. fuel pump, food processing pump, laboratory pump, respiratory suction aide etc.) were analyzed. Each pump's qualities were matched against the following criteria:

1) functionality in bed and in wheelchair
2) portablity
3) 300-500 ml volume capacity
4) maximum pressure of 600 mmHg (based on pouch tolerance)
5) ability to manage mucus secretion

After considering the alternatives, the DeVilbiss Vacu-Aide Portable Aspirator was chosen. It had a vacuum range from 50 to 375 mmHg and a 1000 ml collection bottle volume. Thus, its applied pressure range resided in the region tolerable by the walls of the pouch and the capacity was sufficient for urinary waste extraction. In addition, this suction machine was designed to handle mucus secretion from the trachea, and so was assumed to be able to manage pouch secretions. Finally, the price of the portable suction aide was within the budget specified by the insurance company.

Results

The client was extremely pleased with the Vacu-Aide Portable Aspirator. In later follow-ups, the client highlighted many good aspects of Vacu-Aide. For example, it could be soap-washed daily. Also, sterile catheters and other tubing materials could be readily obtained at medical equipment facilities. In addition, the Vacu-Aide could be battery-operated. Lastly, in traveling situations, the suction aide had compact dimensions that fit well in her wheelchair bag. Perhaps the client's own words best summarized the results: "Everyone with an Indiana pouch should have one of these things."

Discussion

The search for appropriate solutions brought about three important points. First, while the syringe holder was an attempt to alter the distribution of stress and strain on the median nerves, the client reported that the wrist and hand pains remained and so adapted syringe operation was not well-received. It is possible that underlying this rejection was the client's desire to replace syringe operations completely.

Second, when identifying the best mechanical pumps to replace syringe operations, it is much preferred to employ equipment used for other medical application rather than non-medical equipment. Medical equipment is designed with specific criteria suitable for the human physiology such as biological specificity, pressure sensitivity, and sterilizability.

Third, an important problem requiring attention is the development of carpal tunnel syndrome as a consequence of syringe operations. In the course of this case study, we solicited the advice of the staff in the Urology Research Laboratory for possible laboratory pumps suitable for pouch drainage and irrigation. They were extremely interested in our case especially since several of them had been suffering from hand and wrist pains from daily syringe and pipette operations. Thus, they wanted us to correspond with them if a solution was found. The development of carpal tunnel syndrome from periodic syringe operations seems to be an important issue that needs to be addressed. Perhaps an approach similar to that described here can be developed for applications in laboratories and other environments.

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Adaptive Technology in the Kitchen Area for an Individual Who is Visually Impaired/Blind

Maleshia Jenkins

Abstract

This paper describes many kitchens related devices that will assist an individual who is visually impaired or blind in preparing meals and snacks. The devices perform making tasks and are cost effective. These items are common household items with modifications, adaptive devices and audible cues to assist individuals who are visually impaired or blind from creating any safety hazards. With these devices, individuals who are visually impaired/blind can live independently. By being an advocate for independent living and supporting the manufactures who make these items, we can reduce the biggest fears of individuals who are visually impaired/blind, which are feeling different, disconnect or dependent.

Background

Many people who are visually impaired/blind wish to live independently and make choices over their own lives. Years ago, the level of adaptive technology for this population were a few devices but not many. Through research, advocacy and financial support, many devices and equipment have been created and modified to help these individuals gain the independence they desire. Then, the technology had been created but it was very expensive and hard to locate these items. Currently, some of these items are sold in common appliance stores and special devices can be requested, shipped and delivered by companies who specialized in manufacturing these items. We have come a long way in adaptive technology for the visually impaired/ blind population. But unfortunately, they are still experiencing feelings of being different, disconnected and dependent.

Objective

To identify many kitchens related devices that are cost effective for individuals who are visually impaired/blind and that will assist them with living independently.

Approach

First, I identified kitchens related items that were commonly used by individuals with no visual disabilities. I next identified if modifications have been made on these commonly used kitchen devices. I located several kitchen devices with adaptive technology. I began to compare prices of several devices and created a list of these items. On the list, I identified these devices, gave a brief description of them and indicated the individual and total cost of the devices.

Results

The "Say When" Liquid Level Indicator -- the device is designed for visually impaired/blind population which makes a buzz sound when the liquid is ½ inch from the top. Cost $13.95

Food Bumper-- Snap-on food bumper is designed to keep food from sliding off of the plate when a person who is visually impaired/blind is eating. Cost $2.95

Inner Lip Plate-- A person who is visually impaired/blind can slide their fork or spoon to the edge of the plate for pick up of the food. Cost $4.25

Boil Alert--A heat resistant glasses disk that indicates when a device boils by making a rattle sound. Cost $2.95

Color Coded Measuring Cups--Measuring cups that are colored with raised numbers and letters for tactual assistance. These help visually impaired individuals to identify them easily. Cost $3.95

See and Hold Measuring Cups--Measuring cups with large numbers and white plastic. The numbers are enlarged for individuals who visually impaired can see them better. Cost $3.95

Automatic Peeler--Automatic peeler with rotating blades that will cut food items. Individuals who are visually impaired/blind decrease their chances of experiencing injury from a knife. Cost $11.95

Microwave ovens w/ braille--These microwaves are fast, clean and easy to use. They include brailled templates for control devices. Cost $159.95

Automatic Perk--Coffee pots with automatic temperature controls, heat-resistant handle and water level markers. This device will decrease the risk of injury for someone who is visually impaired. Cost $21.95

Fray Pan w/Braille--Temperatures are indicated with raised dots which control safety hazards. Cost $47.95

Tactile Portion Control Scale--This scale indicates weights with tactile dots. Especially helpful for individuals who are diabetics and they are visually impaired/blind. Cost $19.95

Tactile Meat Thermometer--Fahrenheit demarcations marked with tactile dots. Cost $14.95

Toaster/Oven Broiler--Multipurpose oven w/ high marks indications of degrees. Cost $59.95

Crock Pot--Three setting audible click controls. Cost $32.95

Slicing Guide & Roaster Holder--Knife in grooves for safely slicing food items. Cost $19.95

Flame Tamer/Heat Diffuser--Controls flames of a gas stove. Cost $2.95

Discussion

The list of items above supported my objective by identifying devices that were affordable and assisted individuals who are visually impaired/blind with living independently. The evaluation has been conducted using the criterion for the assessment of Adaptive Technologies which are functional items, easy to use, acceptable in appearance, affordable and provide independence.

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Functional Control and Assistance

THE HEPHAESTUS SMART WHEELCHAIR SYSTEM

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ABSTRACT

The Hephaestus[1] Smart Wheelchair System is envisioned as a series of components that clinicians and wheelchair manufacturers will be able to attach to standard power wheelchairs to convert them into "Smart Wheelchairs." A prototype of the system has been developed and evaluated in preliminary user trials.

BACKGROUND

The needs of many individuals with disabilities can be satisfied with power wheelchairs, but there exists a significant segment of the disabled community who find it difficult or impossible to operate a standard power wheelchair. This population includes, but is not limited to, individuals with low vision, visual field neglect, spasticity, tremors, or cognitive deficits. To accommodate this population, several researchers have used technologies originally developed for mobile robots to create "Smart Wheelchairs." Smart wheelchairs typically consist of a standard power wheelchair base to which a computer and a collection of sensors have been added. Smart wheelchairs have been designed which provide navigation assistance to the user in a number of different ways, such as assuring collision-free travel, aiding the performance of specific tasks (e.g., passing through doorways), and autonomously transporting the user between locations.

STATEMENT OF THE PROBLEM

Despite the increased interest in smart wheelchair research, smart wheelchairs have yet to make the leap from research project to rehabilitation product. A primary obstacle to successfully commercializing a smart wheelchair is the expense of the necessary technology. The goal of the Hephaestus Smart Wheelchair System is to develop an affordable smart wheelchair solution that can be successfully produced as a commercial product.

RATIONALE

Our goal is not to design an entirely new wheelchair from the ground up. Instead, the Hephaestus Smart Wheelchair System is envisioned as a collection of inexpensive components (at first limited to a microprocessor, sonar sensors, and bump sensors) that clinicians and wheelchair manufacturers will be able to attach to existing and newly built power wheelchairs to convert them into smart wheelchairs. The navigation assistance that the Hephaestus System provides to users is based on the navigation assistance behavior developed for the NavChair Assistive Wheelchair Navigation System [1].

A key element of the Hephaestus System's strategy for reducing the cost to the consumer is making the system relatively simple to transfer between wheelchairs. Our intention is for a user to purchase the system once and continue to use the system despite the number of times they change wheelchairs during their lifetime. Reaching this goal will require making the system compatible with several manufacturers' wheelchairs and requiring few modifications to the power wheelchair when mounting the system.

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[1] Hephaestus, the Greek god of fire, craftsmen and smiths was the only Olympian with a disability. Hephaestus was injured when his father, Zeus, flung Hephaestus off Mount Olympus for siding against him in a dispute with Hephaestus' mother, Hera. To compensate for his disability Hephaestus built two robots, one silver and one gold, to transport him.

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DESIGN

The following design criteria have been established for the Hephaestus Smart Wheelchair System:

Respect the user's input as much as possible. At all times, the actions of the smart wheelchair should conform as closely as possible the desires of the user while still preserving the user's safety and comfort.

Preserve the user's safety. There will always be moving obstacles that travel too fast to be avoided or stationary obstacles that are difficult to detect, but the wheelchair should avoid colliding with any obstacles that its sensors are capable of detecting. In addition, a variety of sensors should be carefully positioned on the wheelchair so as to maximize the probability of detecting an obstacle.

Maintain ride comfort. The wheelchair should move smoothly, without sudden starts or stops.

Accommodate a large number of input methods. A tremendous variety of standard input methods have been developed for wheelchairs (e.g., joystick, switch, head motion, pneumatic), and the smart wheelchair should be capable of accepting commands from any of them.

Accommodate significant seating intervention. A large percentage of the target user population is likely to need some form of functional seating support (cushions, lateral supports, head supports, etc.). The system must not interfere with therapists' ability to meet clients' seating needs.

Maintain a modular design. Modular hardware will facilitate adding to or repairing the system and allow clinicians to transfer the system between wheelchairs.

DEVELOPMENT

The prototype of the Hephaestus Smart Wheelchair System is mounted on an Everest & Jennings[2] Lancer2000 power wheelchair. Figure 1 gives an overview of the prototype. As shown in the figure, the Hephaestus system interrupts the connection between the joystick and the controls interface. The user's joystick input is intercepted by the computer, modified by the navigation assistance software, and then sent to the control interface in a manner transparent to both the user and the wheelchair.

The prototype is controlled by a standard analog joystick that, in an unmodified power wheelchair, connects directly to the E&J Specialty Controls Interface (EJSCI), which provides an interface between the wheelchair and a set of potential input and display units. On the Hephaestus prototype, the cord connecting the wheelchair joystick and the EJSCI has been cut in two, to allow the Hephaestus system to intercept and modify the user's joystick inputs. This approach means that the prototype's hardware is already compatible with all Everest and Jennings controls that are designed to interface with the EJSCI.

The Hephaestus system currently makes use of sixteen sonar sensors (configured to detect obstacles a maximum distance of one meter from the wheelchair and a minimum distance of 8 centimeters from the wheelchair). Thirteen sonar sensors are mounted on the wheelchair's lap tray facing forward or to the side of the wheelchair and three sonar sensors are on the battery box facing backwards. Bump sensors represent the ``sensors of last resort" on the smart wheelchair. When a bump sensor is activated it brings the chair to an immediate halt. Bump sensing is implemented using simple contact switches placed on the leading edges of the wheelchair. In the prototype system, up to 24 switches can be mounted on any available surface on the wheelchair.

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[2] Everest and Jennings; 3601 Rider Trail South; Earth City MO 63045

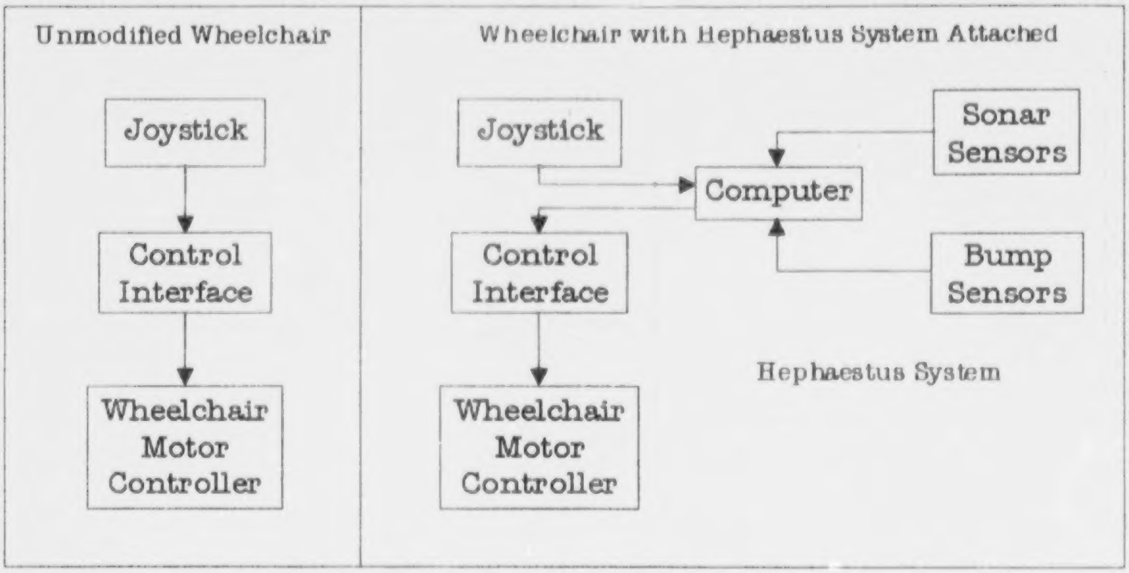
Unmodified Wheelchair
Joystick
Control Interface
Wheelchair Motor Controller
Wheelchair with Hephaestus System Attached
Joystick
Computer
Sonar Sensors
Bump Sensors
Control Interface
Wheelchair Motor Controller
Hephaestus System

Figure 1. Overview of the Hephaestus Smart Wheelchair System

EVALUATION

Several able-bodied and disabled individuals have participated in preliminary user trials of the prototype. During the trials subjects were asked to complete several navigation tasks both with the assistance of the Hephaestus System prototype and without any assistance at all. Results from the trials indicate that the prototype does make it much more difficult to collide with obstacles, but can increase the time required to complete navigation tasks (particularly for skilled wheelchair users).

DISCUSSION

The prototype Hephaestus System represents the first step in our plan to produce a commercial smart wheelchair system. Future work includes replacing the current hardware with less expensive components, developing enclosures to protect the components and facilitate mounting the system on standard power wheelchairs, and designing the necessary hardware to make the system compatible with wheelchairs manufactured by InvaCare, Sunrise Medical, and Permobil. The prototype will also be used as the basis for more basic research in smart wheelchairs, including the use of voice commands to operate a power wheelchair and the long-term effects of a smart wheelchair on a user's wheelchair navigation skills.

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ACKNOWLEDGMENTS

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A WHEELCHAIR-MOUNTED ASSISTIVE ROBOT

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ABSTRACT

In the same way that an electric wheelchair is an effective solution to many of the mobility problems of people with severe physical disabilities, a wheelchair-mounted robotic manipulator may assist them in manipulative tasks. Since such a device operates in close proximity to the wheelchair and the user, it must be completely safe and must not compromise in any way the use of the wheelchair.

A wheelchair-mounted manipulator has been designed and is mounted above the rear wheel of the wheelchair. For the manipulator to be an effective tool it must be easy and intuitive to operate, and is therefore controlled by a familiar joystick input device.

BACKGROUND

There are several ways in which robotic technology can be applied to assist people with disabilities. One approach is to mount the device to a fixed workstation. Another is to mount it on a wheelchair. An earlier device designed by the Institute mounted a manipulator to a simple wheeled trolley (1). The current project, described below, takes the basic upper arm mechanism of the trolley-mounted manipulator, and mounts it to a wheelchair.

STATEMENT OF THE PROBLEM

Having surveyed the needs of people with severe physical disabilities it is possible to draw up a list of activities which might be assisted by a robotic device.

- Eating and drinking: The device will need to be able to handle implements such as spoons, forks, and cups as well as being able to handle some items of food directly.
- Personal hygiene: This might involve tasks such as washing the face, hands, and cleaning teeth, as well as such simple tasks as scratching an itch.
- Work & leisure: This will involve handling items such as CD's, videos, remote controls, chess pieces, books, computer disks and the telephone.
- Mobility: Tasks such as opening doors and operating lift buttons.
- General: General tasks will include picking up objects from the floor or from shelves.

RATIONALE

Many of the tasks described above are common to all assistive robot systems. However some tasks (for example handling computer discs) are more appropriate for a fixed site workstation, perhaps used for a vocational application, while others, especially those identified under "mobility" and "general", are more specific to a wheelchair-mounted manipulator. The trolley-mounted manipulator referred to above has proved to be effective in some applications. This project aims to make the same upper arm design available for a wider range of applications.

DESIGN

Design specification

Interviews with prospective users identified the following requirements and constraints for a robotic device mounted on a wheelchair.

- Must be able to reach to floor and to head height and have good forward reach

- Must not compromise the manoeuvrability of the wheelchair
- Must not obstruct the wheelchair user's vision
- Must not create a negative visual impact
- Must not affect the steering or control of the wheelchair
- Must not affect seat adjustment (or any similar facilities of the chair).
- Must not affect transfers into or out of the wheelchair.

Mock up device

The starting point of the design was the upper arm mechanism from the earlier trolley-mounted manipulator. This operates in a horizontal plane and has a simple vertical actuator to raise or lower it through approximately 0.45m. In order for the wheelchair-mounted application to reach from floor to head height (a range of over 1m), and to integrate with the wheelchair, a different approach was required for the vertical actuator.

The initial design envisaged a single stage vertical actuator mounted on a swinging link that allowed it to be brought from the rear of the wheelchair to the front when required. This was built as a non-working mock-up to gauge the reaction of users.

Vertical actuator development

Both wheelchair users and others who saw the mock-up thought that the single stage actuator was too obtrusive. In order to overcome this, an extending mechanism was designed with two parallel vertical tracks. In its parked (lower) position the whole mechanism does not extend above head height.

It was also found that the use of a hinged mounting required too much clearance to the side of the wheelchair, often not possible in a small room. The manipulator is therefore now mounted in a fixed position above the rear wheels. While not giving quite as much forward reach as had been originally specified this seems a good compromise solution. Mounting the manipulator at the side, close to the shoulder of the user, decreases the visual impact of the device, makes it less liable to damage and does not obstruct the wheelchair approaching a table or desk. Since the weight is over the fixed, rather than castoring, wheels the device does not greatly effect the steering. The prototype is mounted on a "Scandinavian Mobility" powered wheelchair.

Gripper

The end effector for the manipulator is a symmetrically opening gripper. Both grip faces are kept parallel by a parallelogram linkage. An internal spring mechanism allows the grip force to be varied. The gripper is designed to integrate with the aesthetics of the upper arm.

DEVELOPMENT

Upper arm

The upper arm is a direct development from the mechanism used in the trolley-mounted manipulator. The basic structure of the arm is constructed from rectangular aluminium extrusions, covered by plastic mouldings. The design has been developed in order to improve accessibility for maintenance, to decrease costs and to improve the aesthetics.

Electronics

The electronics design is developed from the system used on the trolley-mounted manipulator. A single board PC compatible processor mounted at the base of the arm sends command signals to motor control boards (size only 50mm x 50mm) mounted within the arm.

User Interface Software

The user interface must allow a person with restricted control ability to control a complex device with 6 degrees of freedom. The approach taken is for the user to control the manipulator in real time with a two-degree of freedom input device (such as a joystick, for example). The degrees of freedom of the manipulator are represented on different menus, displayed on a LCD screen. The interface software enables the user to move easily between several menus, and select the appropriate direction of movement of the manipulator.

EVALUATION

Evaluation is an integral part of the design process. The preliminary concepts for the vertical actuator were mocked up for users. The interface software has also been tested by users (implemented on a laptop PC) and valuable feedback incorporated into the design.

When the prototype device is assembled it will undergo brief evaluations with a number of local volunteers. Since different volunteers use different wheelchairs, the device will initially be mounted on a trolley that can be wheeled up to the wheelchair to simulate its final location. Following further development, particularly in the area of integration with different wheelchairs, three volunteers will test the prototype for a longer period.

DISCUSSION

At the time of writing the prototype is being assembled, and initial evaluations by users are planned for early in 1999. Funding has been obtained for the evaluation and continuing development for a further year.

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ACKNOWLEDGEMENTS

The authors are grateful to the Southern Trust for their generous support of this work. A panel of 29 electric wheelchair users has given vital user input to the project. The authors also acknowledge the contribution to the project from the technical staff at the Institute, particularly Martin Rouse (Mechanical Workshop) and Simon Gale (Electronics Laboratory).

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DEVELOPMENT OF A MOBILE ROBOT WALKING AID FOR THE FRAIL VISUALLY IMPAIRED

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ABSTRACT

This paper describes the development of a mobile robot walking aid specifically aimed at addressing the needs of frail Visually Impaired People (VIPs). Frailty makes the use of conventional mobility aids difficult or impossible and consequently VIPs are heavily dependent on carers for personal mobility. In the context of an ageing population and constraints on carers time this level of support may not be available. The sedentary lifestyle that results causes a rapid deterioration in the physical and mental health of the elderly person. The aim of this research is to develop a robot system that will increase the independence of frail VIPs and to allow them to take exercise independently.

BACKGROUND

This paper describes the development of a novel mobile robot to improve the mobility of the elderly visually impaired. Mobile robot technology is typically used in industrial or space applications. It has also been used in assistive technology to develop smart wheelchairs. This device aims to improve the independent mobility of the user without requiring them to use a wheel chair. The aim is to provide a frail VIP with the confidence to take moderate exercise within the confines of a rest home or hospital. This is achieved by providing physical support similar to that of a walker or rollator and the navigational assistance similar to that provided by a carer or guide dog.

STATEMENT OF PROBLEM

Dual disability can severely limit the range of mobility aids a person may use. This is particularly true of the frail VIPs. 75% of VIP's are aged 65+ and frailty is also common among this age group. An estimate of the number of people affected by this dual disability can be gained from analysing the survey data produced by Ficke [1]. His study of nursing home residents in the USA showed that of the 1.5 million residents, 22% were visually impaired and 70% had a mobility impairment. This survey did not investigate the prevalence of dual disability however Rubin and Salive [2] have examined the links between visual impairment and frailty.

RATIONALE

The application of robot technology to the mobility of the blind is a significant challenge given the unfamiliarity of the aged with information technology, short-term memory loss and motivational problems. The underlying principal in the design process was that of *Interactive Evaluation* as described by Engelhardt and Edwards in [3]. This involved regular contact with the users through interviews and field trials of prototypes and subsystems.

DESIGN

The design process was iterative, involving the construction and evaluation of three prototypes and several user interface alternatives. The central concept is that of a walker or rollator with the ability to avoid obstacles and inform the user about the environmental conditions. Figure 1 shows the progression from concept prototype to the final active prototype system. The main design challenges were the development of an acceptable user interface and the development of a shared control system.

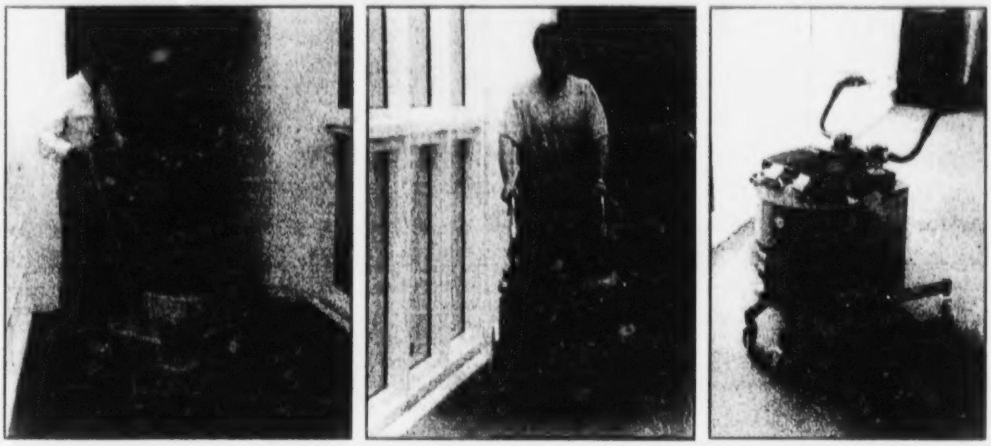

Figure 1: Concept Prototype, Rapid Prototype and Final Active Demonstrator

DEVELOPMENT

In the final system the user interface consisted of a set of user-input switches and a voice input device. User feedback was provided by the user perceiving the movement of the robot proprioceptively and by listening to voice messages that described the state of the environment. The shared controller used a laser scanner and sonar to extract environmental features. These features were combined with user input in a probabilistic reasoning system. The reasoning system used the constraints imposed on the user's actions by the state of the environment to select the most appropriate action for the robot.

EVALUATION

During the development of the Active Prototype three field trials were carried out, in seven locations, involving 30 participants, ranging in age from 55 to 94. During the trials a wide range of design ideas were evaluated and the users were encouraged to suggest alternatives and improvements. The main factors evaluated were the acceptability of the device in the target user group, the user's feeling of security and safety while using the device and the relative performance of different user interface configurations.

Participant's responses in the trials were rated on a five-point scale ranging from 1-Very Low to 5-Very High. Participants in the trials gave positive measures for the acceptability noting that the device was easy to use (3.5) and that they felt quite safe while using the device (3.2). When asked if the device would be useful, the Participants gave they device a mean rating of (4.42).

DISCUSSION

This paper has described research to develop and evaluate a robot mobility aid for the frail visually impaired. It is motivated by the need to maintain the independent mobility of frail VIPs within a structured environment such as a nursing home or hospital. Further research is underway to develop a passive version of PAM-AID [4] and to integrate the current version within and intelligent building system [5]

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DESIGNING A VARIABLE COMPLIANCE JOYSTICK FOR CONTROL INTERFACE RESEARCH

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ABSTRACT

Conventional joysticks are predominately movement sensing. Individuals with upper extremity impairments may perform better if provided a joystick that requires force as well as movement. This paper reviews recent literature and proposes two variable-compliance joystick designs. Both have adjustable spring tension and force and displacement instrumentation. Plans for subject testing are discussed.

BACKGROUND

The proportional joystick is the principal control interface for electric powered wheelchairs and is often utilized to access other rehabilitation technology such as environmental control systems, communication aids, and personal computers. Conventional joysticks use potentiometers or variable inductors to generate proportional signals. Such joysticks can be referred to as 'movement sensitive' because it is physical displacement of the stick that creates the proportional signal. Resistive spring pressure is trivial - merely enough to return the joystick to the center position.

Isometric (physically rigid) joysticks use strain gage or piezo-electric technology to generate X and Y axis signals proportional to the force applied. Isometric joysticks have been compared with displacement sensing joysticks. (1,2,3) Movement-sensitive and force-sensitive joysticks represent the end points of the movement - force continuum. While studies have also been done on damped and hybrid joysticks (4,5), the authors have not found a study on the efficacy of Variable Compliance Joystick (VCJ). A VCJ would possess both force and movement properties.

STATEMENT OF THE PROBLEM

Individuals with athetosis or tremer often have difficulties manipulating conventional joysticks. Wheelchair designers accommodate for impaired control by developing power wheelchair controllers which use microcontrollers to place limits on speed, turn rates and adjust motor torque on uneven terrain.(6) A limitation of this solution is that the control enhancements are performed outside the joystick and are not available if the consumer should want to use the same joystick to accesss another type of assistive technology such as computer or voice output communication aids. Users of assistive technology operate an average of four devices and favor the use of an integrated, (single) control system. (7)

For several years, researchers at the Human Engineering Research Laboratories have been developing and investigating a force sensing joystick with a built in microcontroller.(8) These investigations have focused on comparing the benefit of a pure force-sensing versus pure movement-sensing controls. Other studies (3) have cited the advantages of a control interface customized to individual needs. The authors are intend to create a design that will permit investigators to quickly vary the compliance during research trials and offer the subject an optimum fit.

RATIONALE

As a joystick is advanced across the movement - force continuum, the amount of voluntary force required to achieve activation will increase while, hopefully, the forces associated with unintended movement will remain relatively unchanged. The result should be a higher signal to noise ratio and better control. It is important that this resistance be carefully selected, too much spring tension would result in unnecessary fatigue of the operator's upper extremity.

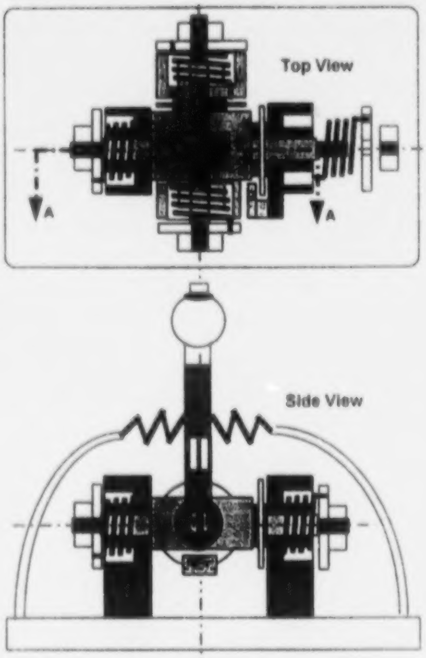

Figure 1. Universal Joint Design for a Variable Compliance Joystick

DESIGN

The design features for the VCJ are:

- size and shape approximating current commercial joysticks;
- both displacement and force signal outputs;
- incrementally adjustable spring tension; and
- individual regulation of the spring on each of the four principal axes

Two design concepts are under development. The first design is illustrated in Figure 1. It uses a universal joint and torsion springs. The preloaded tension on the springs can be individually adjusted by rotating and locking the endplates on the spring chambers. Movement is detected by two shaft encoders; one for the X axis shaft and one for the Y axis shaft. Force will be detected by laminating strain gages to four facets milled on the main shaft. This design requires several pivots and seven to ten precision parts.

A second design is illustrated in Figure 2. The joystick shaft is providing two degrees of freedom by means of a commercially available spherical joint. As in the first design, force data is collected by strain gages bonded to squared off facets on the shaft. Below the spherical joint the shaft is threaded. A central hub with a clearance hole may be positioned anywhere on this shaft and secured by lock nuts. This hub provides a variable length moment arm for the spring action. The perimeter of this hub is drilled at 90 degree intervals to receive the wire end loops of four tensile springs. The aluminum enclosure has four vertical slots cut through the walls. A short stud with lock nuts passes through each slot and provides the tie point for the other end of each spring. To immobilize the joystick for force-only testing, a jam nut is provided just below the spherical pivot.

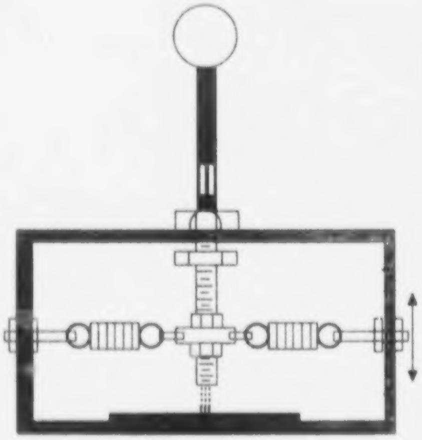

Figure 2 Spherical Joint Design Variable Compliance Joystick

To detect the position of the spherical joystick, a dual axis optical PIN detector plate, as described by Gehlot (9), will be mounted on the floor of the enclosure. The lower end of the stick will be drilled to receive a small focused beam lamp. When the light strikes the plate, the plate will respond with proportional voltages on two output pins

DEVELOPMENT/DISCUSSION

A prototype of the spherical joint VCJ is currently under construction. A digital photo is shown in Figure 3. An interesting issue is how to prevent the joystick shaft from rotating on its longitudinal axis without constraining the two degrees of freedom required. The current plan is to place a low friction bearing between the hand grip and the shaft to prevent the operator from inadvertently twisting the shaft. The universal joint design will be built in the event quality pilot data cannot be collected with the spherical bearing prototype.

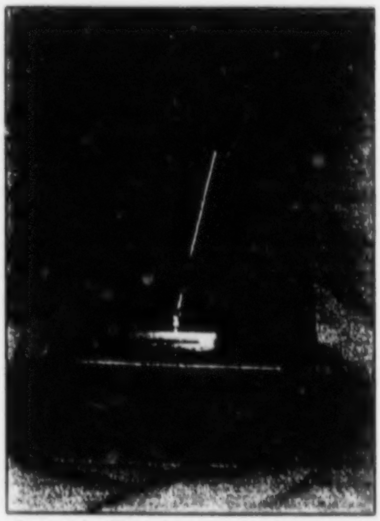

Figure 3. Prototype under Construction

EVALUATION

The first author has completed a doctoral dissertation proposal to test this joystick with subjects who have athetoid cerebral palsy. The subjects will use the joystick to perform computer screen tasks, e.g. icon acquisition and object tracking. The host computer will record joystick forces, joystick displacement and the resulting cursor movements.

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PROVAR REHABILITATION ROBOT SYSTEM ARCHITECTURE

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ABSTRACT

This paper describes the implementation of a robot control architecture that combines a manipulation task design environment with a motion controller. The ProVAR desktop manipulation system is an assistive robot for individuals with a severe physical disability. The novel simulation/ preview user interface concept is based on two built-in characters (Jiminey and Pinocchio) to play the roles of consultant and down-to-earth robot arm. This team-based interface concept maximizes user performance and comfort in controlling the inherently complex mechatronic technology.

BACKGROUND

The precursor to ProVAR was DeVAR, the desktop vocational assistant robot [1]. The two share a common geometry: a small robot arm mounted on an overhead track suspended above a desk work-surface. DeVAR had a simple graphic interface and voice recognition unit. Tasks were position-based and, as a result, "brittle", not robust, since any small difference in position of an object could cause the task to fail [2]. ProVAR is designed to handle such problems through force-based control.

For recent reviews on other rehabilitation robots, see [3], [4]. MASTER/RAID is similar to DeVAR, but is set up in its own separate workspace adjoining the user's workstation. The commercially available MANUS wheelchair-mounted robot allows motion-level control in unstructured settings; the Movaid project is developing a home use mobile robot.

STATEMENT OF THE PROBLEM

The primary users for a robot such as ProVAR are individuals who have a physical disability but can communicate clearly and have normal cognitive ability, such as with high-level spinal cord injury (SCI). There are about 89,000 individuals with quadriplegia as a result of a spinal cord injury in the U.S. today, with an estimated 3,000 new injuries each year. Life expectancy is close to normal, which translates to a long-term need for technology aids and attendant care. It is estimated [5] that there are 150,000 disabled people in the U.S. who could be candidates to use a robotic assistant.

RATIONALE

Assistive robots allow a person with a severe physical disability to perform Activities of Daily Living (ADLs) and vocational support tasks. Typical tasks are handling books, medication, paper, computer media, food and drink, as well as controlling office equipment. ProVAR facilitates task construction and execution by non-technical operators and integrates sensor feedback to the robot's environment interaction and object handling.

DESIGN

ProVAR consists of a Staübli (Duncan, SC) PUMA-260 manipulator mounted on an overhead, 1m long transverse track (see figure 1). The arm carries an Otto Bock (Minneapolis, MN) Greifer™, a parallel-jaw device with pinch, grasp and hook prehension, and augmented with an encoder and FSR

(Interlink, Camarillo, CA) touch sensors. The robot carries capacitive proximity sensors [12] to detect obstacles.

The interface has several design layers: the physical layer provides the user with access to the operating system of the interface computer. ProVAR uses ViaVoice voice recognition (IBM, White Plains, NY) and the HeadMaster™ head motion tracker for cursor control (Prentke-Romich, Wooster, OH). The second layer is the Windows-NT operating system software. The third layer is the simulation/preview software written in HTML, Java and VRML, and accessed through a WWW browser (see figure 2). This layer communicates to the control computer for robot commands and status.

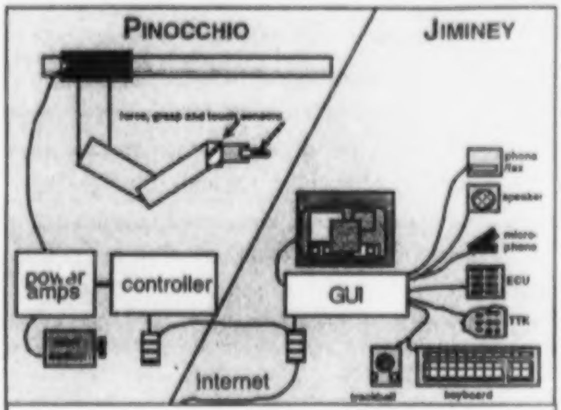

PINOCCHIO
JIMINEY
force, grasp and touch sensors
power amps
controller
GUI
Internet
phone fax
speaker
micro-phone
ECU
TTK
trackball
keyboard

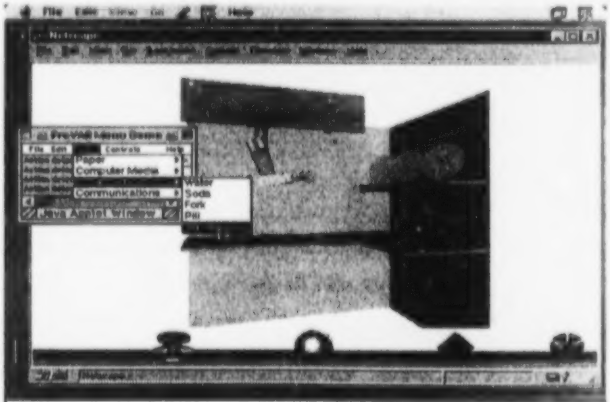
Figure 1. ProVAR System Components

DEVELOPMENT

Dual-character user-interface: The theory of Social Responses to Communication Technologies explains that an individual's "interactions with computers, television and new media are *fundamentally social and natural,* just like interactions in real life" [6]. This was a strong influence on ProVAR's interface design. A second design feature is the team-approach to design, learning and problem-solving [7]. Based on these two concepts, ProVAR's robot interface [8] is divided into two parts: characters named Pinocchio (the robotic arm) and Jiminey (the GUI). The user, Pinocchio, and Jiminey will work together to complete the desired tasks.

Controller design: A 266 MHz Pentium-Pro-based computer uses hardware from Trident Robotics (Minneapolis, MN) for the real-time control. An ATI Mini-40 F/T force sensor (Garner, NC) is mounted at the PUMA-260's wrist. Communication with the proximity and touch sensors occurs over a two-stage SPI/CAN-bus network that features a 500 Hz sample rate.

A robot library written in C++ has been developed to provide the control functions (e.g., kinematics, forward and inverse dynamics, trajectory generation). Under the real-time operating system QNX (Toronto, Canada), the controller has timer and watchdog routines and drivers for encoder, D/A, A/D and force sensor communication. The control structure is based on the operational space formulation [9] for unified motion/force control and makes use of artificial potential fields for real-time, sensor-based trajectory modifications.


File
Edit
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ProVAR Menu Demo
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Communications
Water
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Java Applet Window

Figure 2. VRML Model of Robot Workstation

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EVALUATION CONCEPT

User testing is pending. It will be based on Nielsen's "*discount usability testing*" method [10], which entails in-depth testing with a small number of subjects in a heuristic evaluation of system function. This method was developed for *complex* software products, for which traditional methods often fail to assess system performance and identify interface failure modes.

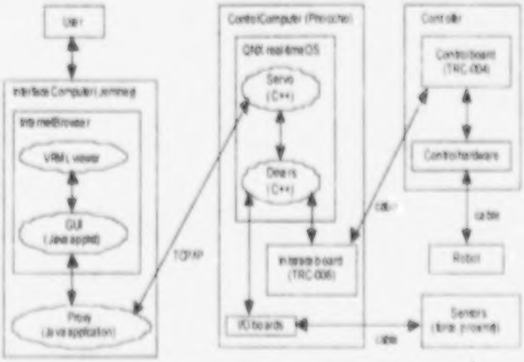

Figure 3. Hardware/Software Architecture

DISCUSSION

ProVAR's design provides a safe robotic assistant in a semi-structured office workspace setting for a person with a severe physical disability. The user interface has design provisions for handling inherently complex interactions through team-based problem-solving approach concepts. The real-time controller allows robust interactions with the environment in the face of unforeseen situations. Evaluation studies will seek to validate the design choices and provide guidance toward the development of a commercially and technically viable rehabilitation robot product.

ACKNOWLEDGMENTS

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DESIGN AND PRELIMINARY EVALUATION OF FUNCTIONAL UPPER ARM ORTHOSES.

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ABSTRACT

This paper addresses the design and evaluation of functional orthoses for the upper arm. We have presented the drawbacks of the currently used balanced forearm orthosis (BFO), obtained from user surveys and our engineering perspective. Details about the two prototypes that we are currently designing are presented, along with some preliminary results obtained from user trials. Discussions about the design choices, along with variations that were tried before the current prototypes were developed are presented. During trials with one of the developed prototypes, a user who previously could not move his arm without assistance, independently moved his arm in three-dimensional space. This is a marked improvement in the functional capability of the user.

BACKGROUND

This paper addresses problems associated with the development of orthotic systems that support a disabled person's arm and augment his residual motor ability while utilizing his natural sensory feedback. There are a number of disabling conditions, such as Duchenne muscular dystrophy (DMD) [1], and spinal muscular atrophy (SMA), that result in the loss of proximal strength. This loss leaves the person with insufficient muscle power to move his arms in space. These conditions however do not necessarily affect the distal motor control and do not impair the sensory pathways. People affected with such diseases can benefit considerably from a system that supports their arms against gravity and provides powered assistance when and if there is insufficient muscle force to perform functional tasks.

Articulated upper limb orthoses have been studied for many years. These range from the mobile arm support to computer controlled, multi-degree-of-freedom devices. Among the earliest and most accepted passive family of devices is the balance forearm orthosis [2]. Various forms of overhead slings and spring-loaded mechanisms have also been used to assist arms with proximal weakness. Externally powered orthoses were also prototyped including: Engen's pneumatic orthosis system, Case Institute of Technology's computerized orthosis, both controlled by wrist-activated switches, and the Rancho "Golden Arm", controlled by an array of tongue and eye switches [3]. None of these powered orthoses reached an acceptable level of performance.

STATEMENT OF PROBLEM

The goals of this study are the design and fabrication of upper extremity orthoses, and the preliminary evaluation of these devices by potential users. The electromechanical functional orthosis developed will provide for three-dimensional spatial movements of the hand. The unique feature of the device will be that it provides gravity compensation in the vertical direction, allowing a person with weak musculature to maneuver his or her arm in space with minimal effort. This is a considerable improvement over currently available options such as the balanced forearm orthosis, which provides for movement only in the horizontal plane. The system will include electrical motors that will act as amplifiers of strength for people with DMD and SMA. The device will be directly controlled by residual muscle capacity of the user.

RATIONALE

The current prototypes are based on the feedback received during various meetings with potential users. Taking what we have learned from previous attempts and simplifying the design will increase user acceptance. One of the desired features is to keep the device as minimally visible and unobtrusive as possible. Hence, we have designed the orthosis as a mechanized armrest so that the device appears to be an integral part of the wheelchair. This design philosophy also allows for a more natural flow between tasks, including those that would not normally require a functional orthosis. One such task that the users specifically requested was to maintain the use of the wheelchair joystick without doffing the orthosis. Our development is based on the premise that power assistance may need to be added later on. Therefore, we have designed each joint of the orthosis such that it can serve either as a passive or powered joint.

DEVELOPMENT

Our first anthropomorphic prototype [4] was very bulky. The cables used to provide the spring - necessary for gravity compensation - added considerable friction to the movement. Any misalignment of the arm to the orthosis caused significant problems during actual movement. The original version did not sufficiently account for variability in arm dimensions of different users.

Currently three users participate on a regular basis with the designers and provide feedback on the prototypes developed. At the first meeting we presented them witn various sketches and based on their input we developed two prototypes: a functional armrest concept and a conical design. The first prototype, the armrest design shown in Figure 1, was tried with two users. This concept consisted of using a vertical gravity compensated movement in concert with a radial sliding mechanism. Since it took the place of the users armrest, fitting into the "standard" tube mounts, the perception that the device was anything but an armrest was minimized. The concept of "replacing" the armrest proved intriguing to the users, but in practice proved troublesome due to the non-standard nature of armrest mounts. Another potential difficulty in the design is the binding leverage forces created by the separate vertical and horizontal mechanisms. The horizontal radial sliding mechanism also interfered with the wheelchair joystick.

Figure 1.
Armrest prototype with user.

The conical design overcomes some of the mounting constraints because it attaches to the backrest. It is the least obtrusive of all the designs as it is tucked away at the back of the wheelchair and the users arm hides the mechanics most of the time. This concept consists of one ball joint assembly attached at the chair back and another at the elbow of the arm brace. A simple telescoping mechanism connects the two joints. Mechanically it is a more efficient solution, eliminating the binding leverage problem inherent in the functional armrest concept. Adjusting for different users' chairs and individual dimensions, which was a significant difficulty with the armrest design, is facilitated in this model by the simplified geometry.

In Table 1, unobtrusiveness accounts for the design's aesthetics, visibility and whether it impeded other user actions. Functionality was defined as the unit's ability to assist the user in performing activities of daily living. The qualification of motion hindrance refers to a particular design's mechanics overly influencing how the user moves their arm from point A to point B. The last column in Table 1 was used to qualify how well suited the device is for provision of passive gravity compensation.

	Unobtrusiveness	Functionality	Motion Hindrance	Gravity compensation
BFO	Poor	Fair	Yes	Poor
Anthropomorphic	Fair	Fair	Yes	Fair
Functional Armrest	Good	Good	No	Good
Conical	Good	Good	No	Good

Table 1. Comparison of the design concepts as evaluated by the users.

EVALUATION

Even though the BFO is a simple device, our surveys [4,5] of potential users have shown that most of them do not like the BFO. The few who do use the BFO, do so only for eating and depend on caregivers for all other activities of daily living. One of the most common complaints is that the user has to doff the BFO and stow it to do other activities, such as driving the wheelchair. The BFO does not stay within the footprint of the chair and interferes with navigation through doorways. Since doffing and donning the device are not typically done by the user, this puts a serious limit on the use and effectiveness of the BFO.

During trials with the functional armrest prototype, a user who could not independently move his arm moved his arm in three-dimensional space without any assistance. This in itself is promising and demonstrates potential for increased independence of a user in performing activities of daily living. Despite the fact that the prototype compensated for gravity and the user could move freely through some of the range, dynamic assistance was needed at other points of the workspace. It was also found that the ability to freeze a joint would be helpful while performing certain motions.

Even though all attempts were made to keep the design adjustable so as to fit many wheelchair designs, it was found to be a challenging task. We plan to provide other techniques to mount the orthosis during the trial phase. In the final design we will have several variations to address the variability of wheelchair mounting details.

DISCUSSION

Although the general design specifications of the functional orthosis have been carefully thought out and addressed with the help of user input, several issues still need to be resolved. There are many activities that could be accommodated by such an assistive device, but our goal initially is to concentrate on the performance of simple tasks of daily living. The users have also stressed that, next to the device being nearly "invisible"; the design should not interfere with the normal functions of the wheelchair or require doffing to do regular activities involving the wheelchair.

Based on user feedback, one of the above designs will be chosen for further evaluation. Five users will be provided with the prototypes, which will be tested over an extended period of time. After a few weeks of usage, we plan on evaluating what new tasks the users have been able to perform. A systematic study will be developed to assess the improvement in everyday activities before and after use of the orthosis. After the successful completion of this phase, we plan on evaluating the impact of using the orthosis early in the disability to study the effects it has on reducing contractures in this population.

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IMPROVING CARDIAC RETURN AND SPASTICITY IN SPINAL CORD INJURY DURING STANDING USING FUNCTIONAL ELECTRICAL STIMULATION

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ABSTRACT

Central hemodynamic responses in 11 individuals with Spinal Cord Injury (SCI) during standing with FES (Functional Electrical Stimulation)-induced leg muscle contractions (active standing) were compared to standing without FES (passive standing). After 30 minutes of passive standing cardiac output (CO) and stroke volume (SV) decreased ($p<0.05$) 21.7% and 23.7 % respectively, total peripheral resistance (TPR) increased 21.7%. Following active standing, CO and TPR remained stable, SV decreased 14%, and heart rate increased 10.5%. Spasticity decreased with active standing and increased during passive standing. FES may be an appropriate adjunctive treatment to standing in individuals with SCI to prevent inappropriate hemodynamic responses.

BACKGROUND

Standing systems are used frequently with the Spinal Cord Injured (SCI) population for the prevention of secondary disabilities. Standing is used to prevent osteoporosis, minimize spasticity, prevent pressure ulcers, prevent joint contractures, and to improve renal, bowel and bladder function.(1) Little research has been done to examine the effect of passive standing in SCI on central hemodynamic responses or the possible use of functional electrical stimulation (FES) on lower extremity musculature to improve hemodynamic responses secondary to improved venous return and to stabilize blood pressure.

FES has been shown to activate the skeletal muscle pump, promote blood flow and reduce venous blood pooling in other patient populations. (2,3) Functioning skeletal muscle acts as a muscle pump, assisting the heart with return of venous blood. Without this venous muscle pump, as in SCI, blood pools in the lower body. This sequestration of blood in the lower body decreases the circulating blood volume and impairs venous return, limiting cardiac pre-load via the Frank-Starling mechanism, thus compromising stroke volume and cardiac output. (4) FES has been investigated in the SCI population to improve venous return in sitting. (5) Others have demonstrated that FES can activate the skeletal muscle pump in calf and thigh muscles to significantly increase stroke volume (+12%) and cardiac output (+30%) in SCI subjects during sitting, using a 1.5 to 2.4 second on/off duty cycle.(6)

RESEARCH QUESTION

The purpose of this study was to determine whether the central hemodynamic responses in individuals with SCI during standing could be altered with FES-induced contractions in the lower extremities during 30 minutes of standing and whether this may also reduce spasticity.

METHODS

Subjects: Eleven individuals, levels C5 to T10 complete or incomplete, six months post-SCI and greater were recruited for this study. The mean ± standard error for: age 36.2 ± 3.0 years, weight 79.5 ± 7.3 kg, height 178.7 ± 3.9 cm, and time post-injury 91.2 ± 19.7 months. Each subject underwent a medical review and ultrasound evaluation of both lower extremities for detection of deep vein thrombosis before being allowed to participate in the study. All the subjects signed an informed consent form in accordance with the Institutional Review Boards of the University of Connecticut and Hospital for Special Care. None of the subjects had a history of disorders of the heart or circulation or any other problems which precluded their participation in the study.

Instrumentation: Two EMPI Respond Select Dual Channel Neuromuscular Stimulators [a] were used to provide surface stimulation to both legs of the subjects during the active standing test. Central hemodynamic responses of each subject during the testing were measured by a noninvasive computerized impedance cardiograph (CIC) Model CIC-1000 [b]. The EasyStand™ 5000 [c] standing system was used to assist the subjects to the standing position.

Procedure: Subjects were secured in the standing system, were slowly brought to a standing position, and remained standing for 30 minutes while measurements were taken. The central hemodynamic variables were recorded during standing at: 0, 5, and 30 minutes. Spasticity was measured pre and post standing using the Ashworth scale. (7) During active standing, FES was applied by eight surface electrodes over the motor points of both legs on the anterior tibialis, gastrocnemius, quadriceps, and hamstrings. The timing and phasing of contractions caused an alternating, overlapping, contraction and relaxation phase 11 seconds on, then 60 seconds off.

RESULTS

Initial standing measures were compared with standing after 5 minutes and 30 minutes during each test. Figures 1,2, and 3 demonstrate these changes. Following 30 minutes of passive standing there were significant decreases in cardiac output (CO) 21.7% ($p<0.05$), in stroke volume (SV) 23.7% ($p<0.05$), and an increase in total peripheral resistance (TPR) 21.7% ($p<0.08$). During active standing CO and TPR remained stable, SV decreased at 30 minutes to 14.1% ($p<0.05$) and heart rate (HR) increased 10.4% ($p<0.05$), with no change in blood pressure. Spasticity decreased 11.9% following active standing and increased 9.3% following passive standing as measured on the Ashworth scale.

Figure 1. Changes in CO during standing.

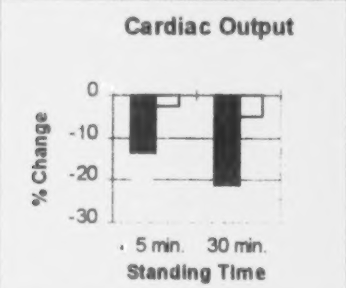


Figure 2. Changes in SV during standing.

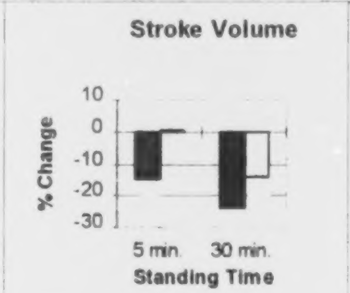
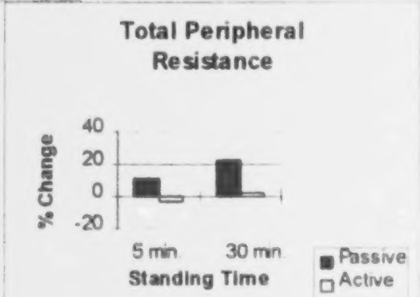


Figure 3. Changes in TPR during standing



*significant p<0.05

DISCUSSION

Using FES during standing in individuals with SCI may effectively activate the venous muscle pump, helping to maintain an adequate SV and CO. The increased TPR during passive standing may be a compensatory response of the heart to increase blood flow and maintain central circulation. In active standing the workload on the heart may be decreased, because of the improved return of venous blood via muscle contractions in the lower extremities as indicated by a stable CO and TPR. Further benefits of standing with FES can be seen with a trend toward reduced spasticity after standing. These findings are consistent with our previous research using FES in subject populations such as CVA, the use of FES during surgery, and the use of FES in able-bodied individuals. (2,3,8)

CONCLUSION

FES may be a beneficial treatment, with the major problem of orthostatic hypotension during standing in the SCI population, by increasing the return of blood to the heart, increasing its pre-load and maintaining blood pressure. Longitudinal studies are needed to evaluate the long term benefits of this intervention, as well as its effect on muscle integrity and osteoporosis.

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INTRAMUSCULAR FUNCTIONAL ELECTRICAL STIMULATION (FES) TO AUGMENT WALKING IN CHILDREN WITH CEREBRAL PALSY

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ABSTRACT

Children with spastic diplegia, cerebral palsy (CP) experience significant gait compromise secondary to muscle weakness and limited soft tissue extensibility. Functional electrical stimulation (FES) may be an intervention which offers the potential to strengthen weak muscles and assist during gait. Four subjects underwent placement of intramuscular electrodes in lower extremity muscles and then used a multiple channel FES system to perform strengthening exercise and FES-augmented walking. Preliminary findings indicate that FES-augmented walking is achievable in these children, and may positively impact some parameters of gait, and point to other areas of possible investigation.

BACKGROUND

Children with spastic diplegia CP present with primary involvement in the lower extremities including generalized hypertonia, muscle weakness and difficulty achieving refined motor responses. Because of their impairments, these children have limited locomotor function and are at risk to develop musculoskeletal complications.

Interventions available to address locomotor deficits and the other musculoskeletal complications common in children with CP include surgery, medications, bracing, and physical therapy, each with inherent strengths and weaknesses. FES has received increasing attention as a modality that may improve gait in those with CP.[1,2,3] Intramuscular FES is able to directly impact activation of weak muscles during specific periods of the gait cycle and, as opposed to surface FES, it is able to isolate superficial and deep muscle fibers.[4]

RESEARCH QUESTION

The purpose of this study was to investigate the direct and carryover effects of percutaneous intramuscular FES augmented walking in children with CP on select parameters of gait including step length, percent of gait cycle in single limb stance, and velocity during gait.

METHOD

Four children, ages 6 to 14, with spastic diplegia who were household level ambulators were recruited to participate in this investigation utilizing a repeated measures within-subject design. All subjects met the selection criteria including presentation of crouched gait, no significant soft tissue restrictions in the lower extremities, hips not at risk for dislocation, spine clinically straight, sufficient tolerance of motor threshold surface electrical stimulation, able to cooperate with research activities, and had assistance to care for electrodes and to set up the FES system.

Each subject had percutaneous electrodes placed in bilateral lower extremity muscles which were found to be weak based on clinical exam and formal gait analysis. Since all four children exhibited a similar "crouched" gait and common weakness patterns, muscles targeted for implantation were similar throughout the group. Muscles targeted were those responsible for hip and knee extension (gluteus maximus, vastus lateralis, and vastus medius), pelvic stabilization in stance (gluteus medius), and in 3 of the children, ankle plantarflexion and dorsi-flexion (triceps surae and tibialis anterior). The electrodes were inserted utilizing a hypodermic technique with the electrodes passed subcutaneously so they exited at a common region on the anterior thigh.

Following electrode placement, subjects performed FES strengthening exercises at home for 4 to 6 weeks to hypertrophy the muscles. Following the conditioning period, development of and training in the use of an individualized FES augmented walking program were implemented.

Stimulation was delivered by a 24 channel research grade stimulator producing a biphasic asymmetrical current at an adjustable frequency to 20 Hz, amplitude to 20 mA, and pulse widths from 0-150 microseconds. Timing of stimulation was controlled during gait using force sensing resistors (FSR's) incorporated into shoe orthoses worn by the subjects during gait. The instrumented orthoses were fabricated with up to four FSR's, one each in the toe, medial mid-foot, lateral mid-foot, and heel. Exact placement of the FSR's was determined using the F-Scan in-shoe sensing system (Tekscan Inc., Boston, MA). Areas of the foot with large ranges of pressure during the desired gait events were used as sensor locations. During stance, pressure transitioned first from the heel, to mid-foot and then to toe, feedback from the FSR's in both shoes was used to turn stimulation on or off for key gait events in each leg. Events detected were initial contact, early and mid stance, and terminal swing. Once the FES-augmented walking program and FSR control were successfully implemented in the laboratory, subjects performed FES augmented walking at home with parental supervision for 4-6 weeks.

Baseline data were collected prior to electrode implantation on spatiotemporal gait characteristics including velocity, step length, and single limb stance. After subjects used FES-augmented gait at home, follow up data were collected under two conditions; walking with FES on and walking with FES off.

RESULTS

Following FES strengthening and training, all four subjects were able to successfully employ FES to walk at home. At follow up, velocity of gait under both conditions (FES on and FES off) were improved in three of the four subjects. (Figure 1) After FES, three of four subjects demonstrated increases in step length of both legs and one subject showed improvement in step length of one leg. (Figure 2) Single limb stance during gait demonstrated a move toward normal levels for the two subjects in which it was measured. Measures of passive range of motion were also taken which suggest that soft tissue flexibility was maintained or increased in hip flexors, hip adductors, and hamstrings in all subjects with the exception of diminished extensibility of the right hamstring in subject 3, and bilateral hip flexors in subject 4. When parents were surveyed by a third party not directly associated with the study, all reported they felt that FES improved ambulation, and were satisfied with their care. One parent would repeat the study only if "better electrodes were available." Three of four parents felt that FES helped functionally in ways other than gait. Some examples were "better balance," "increased stamina," and "able to do more things such as soccer.

Figure 1.

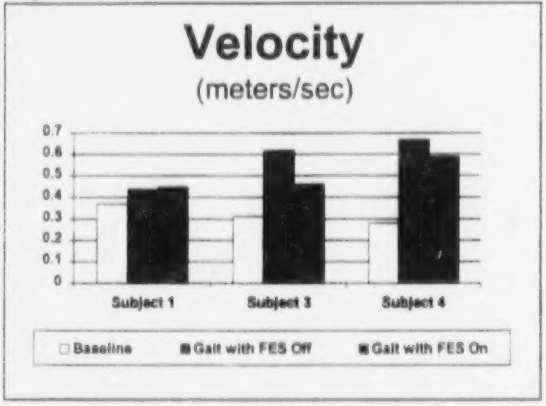
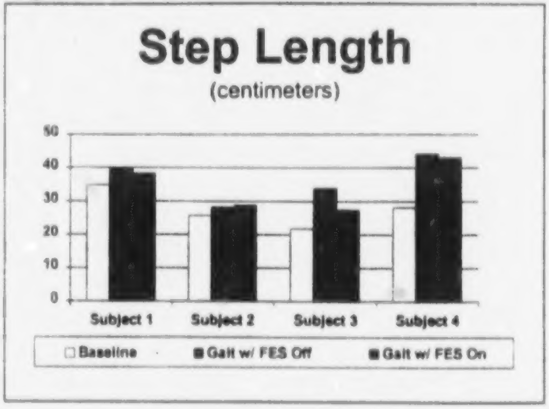


Figure 2.



DISCUSSION

FES augmented walking was achieved and tolerated in these four subjects with some beneficial effects on selected gait parameters as well as soft tissue extensibility. Effects were seen both during walking with FES on as well as with FES off, suggesting carry over effects of FES. If FES is able to improve gait and soft tissue extensibility in this population at a time when performance typically plateaus or declines,[5] it could possibly serve as an alternative to surgery or a means of delaying surgery during a critical period. Parents of subjects indicated that they were pleased with FES as an intervention and perceived an increase in independence in functional skills. Further investigations are indicated to better define possible clinical applications of FES augmented walking in children with cerebral palsy.

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IMPLANTATION OF AN UPPER EXTREMITY NEUROPROSTHESIS IN GROWING CHILDREN WITH C5 LEVEL SPINAL INJURY

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ABSTRACT

This report describes the implantation of an upper extremity neuroprosthesis called the Freehand System in three growing children (ages 7, 11 and 14) with C5 spinal cord injury (SCI). Device implantation was the same as that used with adults except that the leads connecting the electrodes to the internal stimulator included an excess amount to accommodate each child's estimated remaining limb growth. Six month follow-up data with the first two subjects indicate that stimulated muscle responses were maintained in the presence of 1-2 centimeters of limb growth.

BACKGROUND

The Freehand System (NeuroControl Corporation, Cleveland, OH) is a commercially available eight-channel neuroprosthesis designed to stimulate paralyzed muscles of the hand and arm to provide function for skeletally mature individuals with C5 spinal cord injury (SCI). With this system, implanted electrodes are placed in forearm and hand muscles; the electrode leads are routed subcutaneously up the arm and are connected via an in-line connection to an eight-channel implanted stimulator placed in the chest. [1] An external control unit supplies power and stimulation parameters to the internal stimulator by way of a radio frequency signal. Stimulation of hand grasp is controlled by the user with contralateral shoulder shrug sensed by an external position sensor [1].

While the Freehand System has been implemented with both adults [2] and skeletally mature adolescents with SCI [3], growing children have not yet been recipients of this device due to the unknown effect of limb growth on the performance of the internal components. Recent results of animal studies at our institution suggest that motor responses could be maintained with growth using the implanted electrodes of the Freehand System [4] and that excess electrode lead can unravel with growth such that electrodes will remain in position and provide a stable motor response [5]. These positive results using an animal model were the catalyst to implement the Freehand System in growing children with SCI.

RESEARCH QUESTION

To implement and evaluate an upper extremity neuroprosthesis in growing children using sufficient excess lead between the electrodes and stimulator to accommodate limb growth.

METHOD

Subjects

Three subjects with complete C5 motor level SCI according to the American Spinal Injury Association classification were implanted with the Freehand System. Subjects ranged in age from 7 to 14 years (Table 1). Other than the fact that the subjects were skeletally immature, each was considered an appropriate candidate for the Freehand System based on their level of motor function. [2]

Excess Lead Calculations

For each subject, Table 1 shows the estimated excess lead for each of the three possible electrode positions: hand, forearm and upper arm. For each electrode, an estimate of the required excess lead is made based on the number of joints that the lead will cross along its path between the electrode's position in the arm and the connection to the stimulator in the upper chest. For an electrode in the upper arm, the associated lead will cross the shoulder joint only. For an electrode in the forearm, the lead must accommodate growth of the shoulder and elbow. For an electrode in the hand, the lead must account for growth of the shoulder, elbow and wrist. To determine the expected growth of each joint, the skeletal age of each subject was determined pre-operatively by radiograph of the hand (Table 1). From the skeletal age, a growth chart [6] was used to determine the maximum remaining bone growth expected across each upper extremity joint. For subject 2, the stimulator was placed in the abdominal region because the chest area was too small to implant the stimulator. Thus additional excess lead (4 cm) was placed along the lead pathway between the abdomen and upper chest to accommodate growth of the trunk.

Table 1: Expected remaining limb growth and estimated excess lead requirements for each subject based on skeletal age.

	Subject 1	**Subject 2**	**Subject 3**
Chronological Age (At implant)	10 years 9 months	7 years 4 months	14 years 9 months
Skeletal Age (At implant)	14 years	8 years	15 years
Growth Expected -across shoulder	2 cm	9 cm	2 cm
Growth Expected - across elbow	1 cm	4 cm	1 cm
Growth Expected - across wrist	2 cm	6 cm	2 cm
Excess lead - upper arm electrode	2 cm	9 cm	2 cm
Excess lead - forearm electrode	3 cm	13 cm	3 cm
Excess lead - hand electrode	5 cm	19 cm	5 cm

Implantation of the Freehand System

The implementation of the system included implantation of 8 electrodes and the stimulator, the placement of excess lead, and several reconstructive surgical procedures designed to enhance the effectiveness of the system. [3] Eight muscles were implanted with either an epimysial [1] or surgically-implanted intramuscular electrode [7] and were chosen for each subject based on the ability to provide the best stimulated grasp and release. All subjects had the flexor pollicis longus and adductor pollicis muscles implanted for thumb flexion and adduction, respectively, and the flexor digitorum profundus implanted for finger flexion. Each subject required a tendon transfer of a paralyzed but excitable muscle for stimulated wrist extension due to the partial or complete denervation of the radial wrist extensors. Transferred muscles were the abductor pollicis longus (subject 1), flexor carpi ulnaris (subject 2), and flexor digitorum superficialis (subject 3). Other muscles implanted included the pronator quadratus, extensor pollicis longus, abductor pollicis brevis, triceps and palmaris longus.

For each electrode, once the optimal position of the electrode within or along the muscle was determined, the length of the electrode lead pathway was measured with the appropriate excess lead then added to accommodate growth (Table 1). The excess lead was dispersed along the lead pathway with the greatest proportion placed in the upper chest and upper arm with a small amount in the forearm.

Following surgery the arm was casted. At six days post-surgery, the cast was removed and a 1 hour daily stimulation exercise routine was initiated to increase muscle strength and endurance. At four weeks post-surgery, the exercise time was increased to 4 hours each day. This exercise program was continued throughout the course of the study.

Measures

At 1 month and 6 months after the implant, 2 to 4 sessions were conducted during which the threshold pulse duration (pulse duration at which a muscle contraction is first visible) was measured and a manual muscle test was performed to measure stimulated strength. In addition, radiographs of the upper extremity and chest were taken immediately after implant and at 6 months follow-up to determine bone length and to measure unwinding of excess lead.

RESULTS

As shown in Table 2, data were collected for subjects 1 and 2. (Subject 3 is one month post implant.) After six months, limb growth of 2.1 cm and 0.8 cm was measured for subjects 1 and 2, respectively. No trunk growth was measured in subject 2. Threshold pulse durations were not significantly different for either subject's 8 stimulated muscles over the 6 month period as determined by a paired t-test. For both subjects, results of the manual muscle tests indicated that the stimulated strength of each muscle was unchanged or improved secondary to exercise. Lead unwinding in the upper arm was observed in subject 1 but due to the small amount of growth in subject 2, lead unwinding could not yet be visualized.

Table 2: Upper extremity growth at 6 months after implant and the average threshold pulse durations at 1 and 6 months. According to a paired t-test, average threshold pulse durations were unchanged in the presence of limb growth for both subjects.

	Growth - Humerus	Growth - Radius	Total Growth		Avg Threshold (1 month post surgery)	Avg Threshold (6 months post surgery)	p-value for paired t-test
Subject 1	+ 1.1 cm	+ 1.0cm	+ 2.1 cm	Subject 1	6.8 +/- 3.1 usec	6.4 +/- 2.6 usec	p = 0.53
Subject 2	+ 0.6 cm	+ 0.2 cm	+ 0.8 cm	Subject 2	8.7 +/- 4.6 usec	6.4 +/- 1.9 usec	p = 0.07

DISCUSSION

These preliminary data suggest that performance of the stimulator and electrodes have been unaffected by the small amounts of growth to which they have been thus far exposed. For each subject, follow-up measures will be performed annually until skeletal maturity is reached.

Based on our previous experience measuring stimulated muscle responses and lead unwinding in growing animals [4,5], should growth adversely affect performance, it should be clear from the measured variables. The threshold pulse duration, which is considered an indicator of electrode stability [4,7], would greatly increase and the stimulated muscle strength would decrease. In addition, adjacent muscles would be excited prematurely. Insufficient unwinding of excess lead and migration of the electrode from its original position would be evident by radiograph.

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TOTALLY IMPLANTED FES FOR UPRIGHT MOBILITY IN AN ADOLESCENT WITH PARAPLEGIA

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ABSTRACT

A completely implantable functional electrical stimulation (FES) system may provide a more efficient means of upright functional mobility for people with paraplegia. Preliminary results have shown a decrease in the time required to complete several important functional activities as well as an increase in user satisfaction when FES is compared to long leg braces.

BACKGROUND

Persons with paraplegia are commonly prescribed long leg braces to provide upright mobility. Bracing options include knee ankle foot orthoses (KAFO), hip knee ankle foot orthoses (HKAFO), and reciprocating gait orthoses (RGO). Literature cites high user abandonment of these devices with common reasons including difficulty in donning, bulkiness beneath clothing, poor fit into the wheelchair while wearing, and skin breakdown (1,2). Functional electrical stimulation (FES) provides another option for persons with paraplegia that may address some of these issues and may also provide added physiological benefits as well as increased ease of use (3).

Both surface and percutaneous FES systems (4) have been effective in providing standing and limited ambulation using reciprocal or swing through gait patterns. Surface systems are the least invasive but also the least reliable in terms of consistent electrode placement. Percutaneous systems allow for more consistent muscle responses and have demonstrated high reliability over time. However, these systems are intended for research purposes and are not intended to be used as permanent clinical systems.

RESEARCH QUESTION

The objective of this study was to compare the utility of a completely implanted FES system and ankle foot orthoses (AFO) to the utility of KAFO for a variety of functional upright mobility activities in an adolescent with paraplegia. In addition, this study compared user satisfaction based on self selected mobility goals with FES and KAFO and examined the user's perception of the FES assistive technology.

METHOD

The subject was a 14 year old male who sustained a T10 SCI in an MVA at age 2 years, 8 months. Prior to participating in the study, he was a limited community ambulator with KAFO.

An 8 channel stimulator was surgically implanted beneath the skin on the lower abdomen and electrode leads were tunneled subcutaneously to the targeted lower extremity muscles. The stimulator delivers a stimulation waveform with a frequency up to 20 Hz, amplitude to 20 mA, and pulse width to 200 microseconds. Four electrodes were implanted per leg to achieve knee and hip extension and hip abduction. Knee extension was stimulated through implanting an electrode near the femoral nerve to recruit all of the vasti muscles through one electrode. To prevent unwanted hip flexion from the rectus femoris, this muscle was released from its origin on the anterior inferior iliac spine. Stimulated hip extension was obtained through implanting both the gluteus maximus and the posterior fibers of the adductor magnus in order to maximize upright pelvic stability. Hip abduction was achieved through implantation of the gluteus medius. This combination of muscles allows the subject to ambulate using a swing through gait pattern with forearm crutches. As no muscles below the knee are stimulated, AFO are worn during ambulation to protect the foot and ankle complex.

To control and power the internal stimulator, an external control unit is worn around the waist. Through the control unit, the subject selects the desired patterns for exercise and standing/walking. Stimulation patterns are communicated to the internal stimulator by a radio frequency signal using an antenna placed directly over the internal stimulator. Standing and walking are achieved through continuous stimulation of the implanted muscles to allow a swing through gait pattern.

Following the surgical implantation of the FES system and a 4 week immobilization period, all implanted muscles underwent a 4 week period of strengthening and endurance training with the system. The subject then received equal training in 7 upright mobility activities with KAFO and FES. Following demonstration of 3 consistent trials for each activity, five repeated measures were obtained. Activities were scored based on time, level of independence, the preferred mobility mode (KAFO or FES), and the subject's perception of time and effort. T-tests were applied to compare the mean times between mobility modes and median independence scores were calculated.

Satisfaction data were collected with FES and KAFO via the Canadian Occupational Performance Measure (COPM) (5) for activities that were self-selected by the subject. The test is scored based on a Likert scale with 1 representing "cannot perform" and "not satisfied" and 10 representing "can perform very well" and "very satisfied." The Quebec User Evaluation of Satisfaction with Assistive Technology (QUEST) (6) was administered to evaluate the user's perception of satisfaction with and importance of specific characteristics of the FES system. This tool utilizes a 6 point scale with 1 denoting "no importance" or "not at all satisfied" and 5 denoting "very important" or "very satisfied." A score of six represents "does not know" or "is not applicable."

RESULTS

With FES, the subject required significantly ($p< 0.05$) less time to don the system, walk 6 meters, stand and reach a high object, transfer to a high surface, perform sit to stand, and access an inaccessible bathroom stall (figure 1). For every activity, independence scores were the same with FES and KAFO; modified independence was required for all activities except system donning, in which the subject demonstrated complete independence. FES was preferred by the subject for all tested activities. With FES, the subject also reported perceiving less time to don the system and complete the inaccessible bathroom transfer and less effort to perform the 6 meter walk, the high reach, and the inaccessible bathroom transfer.

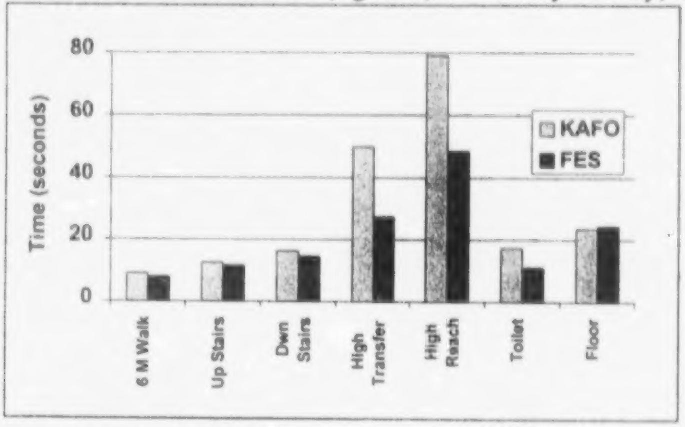

Figure 1: Mobility Activities

COPM testing showed that the subject rated his performance with FES as "well" or "very well" for 75% of his self-selected activities while rating the activities with KAFO as "somewhat well" or "well." With FES, he reported being "very satisfied" with 90% of his activities while only "satisfied" with KAFO.

Results of the QUEST showed that the subject rated variables such as maintenance, safety, and multipurposefulness as very important characteristics, and that he was "more or less satisfied" to "very satisfied" when rating the FES system on these. The subject reported 50% of the variables as "quite important" and was "quite satisfied" with all but one where he was "more or less satisfied." Overall, the subject was highly satisfied with the performance of the system. He was least satisfied with the weight and appearance of the external control unit and the battery pack but did not assign any score less than 3, which represents "more or less satisfied."

DISCUSSION

FES in conjunction with AFO was comparable to KAFO in level of independence for this subject and decreased the time required to complete several functional activities. The most notable time effect was seen with the sit to stand transition, which was timed as part of the high reach and high transfer activities. Importantly, this subject preferred FES for each activity tested and reported increased satisfaction in performing activities with FES. In addition, he was "highly satisfied" overall with the use of this assistive technology. FES affords the subject an adjunct to the wheelchair, increasing the opportunity to easily access areas that are typically inaccessible.

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Public Policy and AT Education

FORTUNE - A EUROPEAN PROJECT TOWARDS EMPOWERMENT OF USERS' ORGANISATIONS IN R&D

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ABSTRACT

In European R&D programmes a new emphasis on user participation is formulated. During the Technology Initiative for Disabled and Elderly user involvement and user participation is recognised as a basic principle for all projects. The programme evaluation realised, that "the most successful projects had the enthusiastic and active involvement of established, formal user organisations"[1]. Therefore it recommended, to make skilled resources available to the projects, by future actions. The FORTUNE project responds to this issue. FORTUNE is a support action organised as a training and networking for end-users who have a backing form their organisation. After the initial training the FORTUNE graduates will offer support to R&D projects.

BACKGROUND

FORTUNE concentrates on the growing group of customers and with disabilities and high age. Although the R&D community is in principle prepared to interact with these users, not enough skilled users from user organisations are available to act in the R&D context in a professional way. For many European user groups a barrier for participation in European R&D is their voluntary character and internal structure, which is not prepared for the procedures in European R&D. FORTUNE takes up these problems and bridges the gap between R&D and users' organisations.

RESEARCH QUESTION

The objective of this Project was to improve the level of participation of end-users with disabilities in the R&D process. The gap between the know-how of the end-users and the culture of R&D technologists should be minimised. Therefore, FORTUNE supports the participation of well trained users (representatives of user groups) for full participation in R&D. The exchange of experience between R&D teams and user organisations and creation of an information network of users is facilitated.

METHOD

The core of the project is the users' qualification for full participation in R&D programmes and projects, with the help of peer user experts and assistive technology and project management specialists. The methods and contents for the training courses are taken up and refined from available methods and experiences, e.g. [2,3]. A European exchange is implemented by networking of user organisations and participation in the Telematics programme. An experimental environment that permits interaction between users and creators is set up. Pilot assessments, support to projects and networking enable the refinement of the training.

Training

The training aims at the empowered participation of end-users (backed on organisations) in R&D. The participants for the training are nominated by the organisations of end-users and finally selected of the umbrella organisations, who are partners in FORTUNE. Thus user organisations have full control about the nominations. They also support the trainees throughout the training in a tutorial concept. Empowerment is mostly connected to competence in knowledge and communication. Basically we consider the end-users to be experts (user experts) in their experience of living with a disability in a environment full of obstacles. And also being experts in finding practical solutions technology for activities of daily living e.g. by usage of assistive technology. So the user experts have knowledge and competence in this domain. However, usually they are not involved in R&D and have no knowledge about how work in this field is performed. Therefore, the end-users should gain understanding about their role in R&D, of the R&D process, of assistive technology and of methodology through the training. The restricted training time concentrated in this respect on the most relevant knowledge domains, as terminology, implementation of AT, critical factors of service delivery, value chain, R&D process and project work, European context of R&D, role identification, understanding of disability (ICIDH), methods for user involvement.

The FORTUNE training is mainly based on appropriate use of existing methods, and experiences of good practice, collected by the partners and national contacts. The training was performed in two presence training phases prepared and followed up by written information and materials. It is obvious that kind of organisation of end-users is varying in the different countries. Hence, the first training phase was carried out on national level and mainly in mother tongues. This enabled to deal with country-specific issues. The second training phase is international and the training language is English. Here participants have been already confronted with the situation of working on European level with peers from foreign countries.

Interaction with R&D projects

For a success of the training it is very important to implement interaction with real projects. This allows a support to projects, and also gives feedback about the success of the training. Therefore projects have been and are still invited to liaise with the FORTUNE support action. The level of interaction is agreed on a case by case base, where confidentiality is guaranteed. As well national as European projects can apply for the service. TIDE / TAP projects are particularly encouraged to make use of the offer. However, only a restricted number of projects can receive the services. They will be selected case by case, where the main selection criteria consider a good match between FORTUNE graduates and project area. Projects who make use of the FORTUNE services will have the opportunity to provide an evaluation of the support from their point of view.

Organisation and Networking

In FORTUNE important self-help organisations co-operate as partners with knowledgeable institutions skilled in European R&D. The concept of national contacts in the European countries and the involvement of the European Disability Forum (EDF) and AAATE (Association for the Advancement of Assistive Technology in Europe) ensure a European dimension and provide potential for information dissemination. National contacts are installed in 17 European countries installed today. This FORTUNE network is an attempt to exchange information and experiences about empowered user involvement in research and development and related issues. It is intended to expand the network based on email and Internet communications during the course of the project. The network is set up between the project partners and national contacts first. More interested parties such as TAP projects already joined the network. We expect the network to grow further and everyone interested is invited to join.

RESULTS

The project has now performed the national and international seminars with about 40 attendees comprising a very mixture of individuals with a broad experience all linked to a self-help organsiation. During the international seminar the experience of the participants was expanded by construction of knowledge about R&D in an interactive manner (method of problem oriented learning). Although we made very good progress the participants felt that the time was quite short and that there is more to learn. Besides the knowledge, the group elaborated very much on a the spirit of partnership, accepting different points of views and tolerate disagreements. Partnership seems to be the most important factor for a successful co-operation in R&D. The training is now complemented by individual experiences of the candidates with projects on national and European level. On the other side the experience shows, that the research community needs some training in this respect, too. Materials have been set up for trainers and the trainees and data with references to user participation has been collected. More information will be presented to the public in the FORTUNE homepage: http://www.fernuni-hagen.de/FTB/fortune

The user organisations themselves are currently investigating opportunities to exploit the results of the FORTUNE project in their countries. During the AAATE 99 conference (November 1-4, 1999) in Düsseldorf, Germany which will be held in conjunction with REHA-international (November 3-6, 1999), world leading fair on rehabilitation technology, partners of the FORTUNE intend to present and discuss results and experiences of the programme.

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BARRIERS TO EFFECTIVE PRESERVICE AND INSERVICE DISTANCE EDUCATION IN ASSISTIVE TECHNOLOGY

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ABSTRACT

The acquisition of assistive technology knowledge and skills is critical for the professional development of preservice and inservice clinical practitioners. Yet, because of the remoteness of their setting, the hectic pace of their professional schedules, or other factors, accessing appropriate educational opportunities can be problematic. Distance education in assistive technology can be an effective solution. Significant barriers to the delivery of effective distance education exist, however, and these barriers must be removed before the extensive benefits can be realized. This paper summarizes an analysis of those barriers.

BACKGROUND

Definitions. *Distance Education* is a system and a process for providing instruction at a distance. Distance education occurs when (a) an instructor and student(s) are physically separated, (b) an educational institution is involved in the planning of curricula and the provision of student support services, and (c) educational media (i.e., voice, video, data, or print) are used to unite teacher and student and to carry course content across the instructional gap. Distance education includes *distance teaching*, the teacher's role in the process, and *distance learning*, the student's role in the process -- and the desired outcome of distance education (1, 2, 7).

Distance Education Formats. Technology offers an institution of higher education (IHE) and faculty many options for providing education at a distance. This domain can be viewed in terms of the nature of the channels by which information is exchanged between instructor and student (1, 2). From this perspective, there are six major formats for distance education: (a) computer-mediated, sometimes referred to as *computer conference courses* (real time or delayed) and the latest variation, *web-based courses*. This can be an asynchronous or synchronous communication format. (b) 2-way video/2-way audio, sometimes referred to as *2-way interactive video courses*, a synchronous communication format. (c) 1-way video/2-way audio, sometimes referred to as *satellite courses,* a synchronous format. (d) 1-way video/1-way audio, sometimes referred to as *videotape courses,* an asynchronous format. (e) 0-way video/2-way audio, sometimes referred to as *audioconference courses,* a synchronous format. (f) 2-way print, sometimes referred to as *correspondence courses,* an asynchronous format. In practice, each of these formats often includes a multitude of subsidiary formats to support the teacher-student exchange of information, e.g., fax, telephone, e-mail, "snail" mail.

STATEMENT of the PROBLEM

The provision of assistive technology services is a skill-based activity. It requires practitioners with the proper knowledge, skills, and dispositions. An important initiative undertaken in recent years by a number of leading professional organizations concerned with children and adults with disabilities (e.g., ASHA, CEC, RESNA) involves specifying appropriate technology-related standards and validating the skills of clinical practitioners. The availability of adequate professional development opportunities to acquire the knowledge and skills required for credentials and advanced degrees, especially for service providers in rural areas, however, can be problematic. Distance education has great potential to assist in the resolution of this problem (2).

Research on learning effectiveness shows that, *when distance education is designed, implemented, and administered properly*, there are no significant differences between distance learning and learning acquired through more traditional methods -- sometimes distance learning is even better (6). This finding, along with its advantages in reducing the major obstacles imposed by location, time, culture, language, and disability, should provide strong impetus both for increased use of distance education by IHEs to deliver assistive technology instruction to preservice and inservice professionals and for higher-quality outcomes in the distance education courses that are already available. Major barriers exist, however, to the successful realization of either of these objectives.

APPROACH

The approach in this paper is to highlight the major barriers to greater and better implementation of distance education by IHEs in the preparation of preservice and inservice professionals in the area of assistive technology. This discussion is based on a year-long review of the scholarly literature and analysis of local practice that was conducted by an interdisciplinary task force at the University of Delaware. Our analysis has revealed both institutional and personal factors that impede positive change towards effective use of distance education in personnel preparation.

1. Foremost among the barriers to substantive change are negative attitudes about distance education among faculty members and academic administrators (3, 4). As in other areas, the foundation for negative attitudes is often misperception or misinformation. For example, some faculty members and administrators believe that: (a) distance teaching is not real teaching, (b) distance learning represents weaker learning, (c) effective instruction must be live and face-to-face, (d) student-faculty interaction is minimized in distance education, (e) certain subject matter can be taught only in a traditional classroom, (f) some distance education formats eliminate the need for faculty, and (g) academic dishonesty among distance students is frequent and uncontrollable (2, 3). There is evidence to support the contention that each of these beliefs is fundamentally incorrect (5, 7, 8).

2. As large organizations, universities are prone to adopting a "change the individual, rather than the system" orientation to addressing challenges in delivering high-quality education (4). This orientation often means subtly forcing students to accommodate to the existing system in terms of when, where, and how they access the available educational opportunities, and forcing instructors to accommodate in terms of when, where, and how they deliver the instruction, rather than modifying the system to better meet student and instructor needs (5). Formal and well -developed student support systems along with faculty development and support systems are essential to effective distance education. This "system-centered" tendency obviously is directly opposed to a "student-centered" approach, of which distance education is a natural and vital part.

3. A characteristic of academic environments that results from its typical departmental organizational structure is low interdependence among faculty members (8). There are few, if any, requirements and typically only diffused incentives for faculty members within and across departments to collaborate to solve problems, deliver programs, and share expertise. There are even some deeply entrenched *disincentives* for such interaction, e.g., the difficulty in evaluating a faculty member's contribution to a joint effort during annual performance appraisals. The impact of this characteristic on distance education is that it contributes to a fragmented level of expertise in distance teaching in a university at a time when shared expertise and cooperative efforts are greatly needed.

4. During a time when education is very salient in the public eye and popular attention tends to focus disproportionately on negative perceptions, universities and particularly their faculties are sensitive to criticism. These conditions are exacerbated when it comes to distance education. Distance education is often inaccurately perceived as a "new" approach to education, and as a consequence it is prone to receiving skepticism and criticism from the public, and even by administrators and faculty members who are unfamiliar with it. The sensitivity and vulnerability to criticism on the part of University administrators and faculty members can combine to negatively influence their willingness to embrace, or even consider, distance education (8).

5. Distance education activities are quite often not part of the central, core fabric of academic programs. Distance education often operates "on-the-margin" of the institution, e.g., within a unit of continuing education. Some of the reasons for this are detailed above. Another significant reason is

administrative policy, which often equates student learning and academic credit only with a prescribed number of "faculty contact hours" and "classroom seat time," counts distance teaching only as an overload activity for faculty, and does not permit on-campus students to enroll in distance education courses. As a consequence, administrative policy creates practical disincentives for departmental administrators to induce faculty to offer distance education courses.

6. In contrast to the previous point, political and economic pressures can seduce some administrators (and faculty) to embrace a particular form of instruction in an uncritical manner because it is the "hot" topic or "the latest innovation". As a consequence, there is pressure to quickly offer courses in that format without adequate information about the important instructional design factors or even about the efficacy of the approach. The current push to "web-ize" whole certificate and degree programs is a case in point. As the newest format, however, web-based distance education presents challenges that have not been encountered before -- in technical delivery, administration, and instructional design (1). Our analysis has shown that, thus far, there has been a tremendous and alarming mismatch between the intended assistive technology skills to be imparted and the format for teaching them. Courses that can teach only declarative knowledge about assistive technology via the web and CD-ROM are being promoted as imparting assistive technology procedural knowledge, i.e., skills. This can result in a host of serious consequences.

IMPLICATIONS and DISCUSSION

At a time when the acquisition of assistive technology knowledge and skills has an important and heightened focus for clinical practitioners, distance education holds unprecedented opportunities for delivering instruction in these competencies and for improving the quality of their learning experiences. To realize these benefits, however, faculty will need to be skilled and creative scholars and practitioners of distance teaching; students will need to be able to access these educational opportunities in ways that are most accommodative to their individual situations; and academic units will need to administer distance education courses in ways that encourage and support responsible practice. The barriers to these objectives are diverse; yet our analysis has shown that they can be overcome. Strategic planning efforts for distance education in IHEs must include consumers, practitioners, and faculty who are directly involved in assistive technology. Future reports will highlight strategies to systematically address each of the barriers outlined in this paper.

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DISABILITY POLICY ISSUES IN THE CARIBBEAN

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ABSTRACT

The International Labour Organization (ILO) collaborated in the formulation of the United Nations *Standard Rules on the Equalization of Opportunities* in 1992. The emphasis on equal rights and equal treatment was also the main element of ILO Convention 159 which provided the policy framework for promoting and achieving equity in training and employment for people with disabilities. To address these issues, the *Caribbean Programme to Promote Equalization of Training Opportunities for Persons with Disabilities* recently concluded a two-year effort to examine and improve the accessibility to vocational institutes in seven Caribbean countries. This paper summarizes those efforts thus far and provides recommendations for continuing progress, particularly related to the consideration of assistive technology.

BACKGROUND

In 1994 the International Labour Organization (ILO) sponsored a *Regional Technical Meeting on National Disability Policy and Legislation to Promote Equality of Treatment in Training and Employment of Persons with Disabilities* in Port of Spain, Trinidad. Representatives of governments, organizations of and for people with disabilities, and employers and workers organizations attended this meeting. At that time, the Port of Spain Declaration was issued to establish a National Policy on Disability in the Caribbean region. A two-year project supported by the ILO, the United Nations Development Program, the Government of Trinidad and Tobago, and implemented by the National Centre for Persons with Disabilities, was designed to move the agenda forward. The *National Orientation Seminar on Integrated Training* and the *Training of Trainers Seminar* were held in fall 1998 with participants from seven of the countries, including Bahamas, Barbados, Dominica, Guyana, Jamaica, St. Lucia, and Trinidad/Tobago in order to begin translating policy to practice. This paper summarizes the activities, discussions, and action plans completed during the *Training of Trainers Seminar*, held in Port of Spain in November 1998, and includes recommendations for further support of these efforts.

Existing data are limited, but it is generally reported that very few persons with disabilities in the Caribbean region have access to medical, rehabilitative, educational, and work opportunities. For example, Jamaica reports that nearly 90% of persons with disabilities are considered to be unskilled and unemployed. Gaining access to vocational training and subsequent employment is the goal, however related considerations including access to earlier educational opportunities, physical access to the facilities, and strategies for modifying the vocational curriculum need to be addressed.

APPROACH

Almost half of the participating Caribbean countries have approved policies regarding integrated employment and training for persons with disabilities, and the others are in the process of doing so. The following framework, based on the work of the National State Boards of Education (NASBE), was used to structure thinking about these issues to determine the present status and the actions necessary to attain goals in each of the areas.

1. Assessment: How needs are identified
2. Governance: Who makes the decisions; how the priorities are set
3. Content: What is included in services and products that are delivered
4. Professional Development: How individuals and organizations continue to improve their performance, e.g., training, technical assistance, continuing education
5. Funding: How funds are raised, used, reported

6. Accountability: Defining the outcomes, how to measure and report them

Discussions were held to identify the relationships among these components and if they were based on a common vision. Participants from each of the countries stated their underlying values, identified potential internal and external resources, and listed the essential stakeholders who must be involved in creating and implementing their plans. A format for reporting successful case studies of people with disabilities who had gained entry to education, training, and/or employment was designed so that local stories could be shared in future training sessions. Each of these stories included the use of an accommodation that addressed attitudinal or physical barriers.

DISCUSSION

After several days of discussions, the participants identified a number of strategies. For example, in order to target physical access issues, the directors of the vocational institutes planned to include the design of accommodations in the curriculum so that students could construct equipment or assistive devices that could help other students or potential employees access classes and/or jobs. The participants were introduced to the transdisciplinary training model developed at San Diego State University (Sax & Szeto, 1995), and quickly realized that they had an untapped resource. By the writing of this paper, two participants have submitted follow-up plans for incorporating the use of assistive technology and other accommodation considerations in their attempts to increase the integration of people with disabilities in the Caribbean.

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USING THE AAA MODEL FOR PERFORMING ACCESSIBILITY AUDITS

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ABSTRACT

Project IMPACT (Integrated Multi Perspective Access to Campus Technology) is serving as a national demonstration to improve the accessibility of a post-secondary education institution. Implementing Accessibility Audits are one of the activities used to promote better integration of students with disabilities to campus. The AAA Model (Accessibility, Accommodation and Advocacy) was created as a necessary component of successfully auditing the accessibility of functions on campus.

BACKGROUND

In 1997 the University of Wisconsin-Milwaukee began a project called Project IMPACT (Integrated Multi Perspective Access to Campus Technology). The project included a number of strategies and activities to promote a more accessible environment for students with disabilities (1). Thirty-six pairs of occupational therapy students were charged with performing accessibility audits across areas and functions on campus. Table 1 lists these 36 audits. These include functions within the classrooms, computer laboratories, emergency and standard telephones, dormitory functions, bookstore and student union settings and electronic media such as web sites, lecture presentations and distance education materials. The students were given instructions to locate all of the appropriate information they might need which would help them evaluate the accessibility of their assigned area, implement the audit and provide recommendations for increasing accessibility.

OBJECTIVE

The objectives of performing accessibility audits were to identify empirical levels of accessibility of campus function, demonstrate that quantifying accessibility could be performed, and highlight recommendations to the campus community regarding improving the friendliness of campus for students with disabilities

APPROACH

Access Audit teams were sent to their access targets after performing literature reviews and obtaining information on measuring the accessibility of buildings, devices and informational sources. The focus of this project however, was not just accessibility, but was performing the audit and using a reliable and valid process. The questions used in audit were reviewed for their validity based on the best literature and information available. The Access Audit teams began the task eagerly, but generated numerous questions throughout the process that revealed significant issues about accessibility in our field of assistive technology and rehabilitation engineering. The development of the AAA Model (Accessibility, Accommodation and Advocacy) became an important contribution to this study.

RESULTS

During these Accessibility Audits, it became clear that the UWM campus already had significant procedures and resources available to make the campus accessible. In fact, a number of the Access Audit teams returned to the instructor highlighting that the campus was already accessible. On the UWM campus the Student Accessibility Center serves as a resource center for campus and employs full-time personnel specifically for helping students and others on campus to access the instructional environment. Consequently, the Access Audit teams asked, "What are we supposed to do when we discover that our access target is already fully accessible?" The instructor questioned this interpretation and clarified that even though there was a Student Accessibility Center, the campus was definitely not accessible. It became evident that an intervention we were accommodating students in an inaccessible environment. While true accessibility was needed, accommodation was being used.

As a result, the instructor began describing that accessibility was a continuum and the Accessibility Audits should be framed to measure accessibility along the continuum that ranged from no accessibility through accommodating people with disabilities to the point of having a fully accessible environment. The instructor described that accessible environments or functions would mean that an individual with any type of disability (sensory, cognitive, motor accommodations) would be able to equally participate in a given activity without expending additional money, time, training or assistive technology compared to any peer who might be accessing the same functions in that environment.

Table 1

1. Emergency blue light telephone posts
2. Bulletin boards in Enderis Hall
3. Hourly work recruitment posting system
4. Course registration process
5. Timetable - Schedule of classes
6. Cafeteria line in dorms on campus
7. CD references in library
8. Library card catalog system
9. Campus map signs
10. Campus WWW home page
11. Allied Health Professions home web page
12. School of Education information kiosk
13. Business School information kiosk
14. Parking gates - in Union and Sandburg Hall
15. Bulletin boards outside elevators.
16. Clocks in classrooms
17. Menus in Union food court
18. Door plates of faculty offices
19. Push/Pull signage of campus doors
20. Room number signage
21. Building directories of offices
22. Bookstore textbook aisle directories
23. Masters theses and dissertations in library
24. Web Course in a Box multimedia course
25. Student and staff telephone directories
26. Public telephones on campus
27. Course electronic reserve materials
28. Scientific posters outside offices and labs
29. Enderis room 980 computer lab
30. Campus general access labs
31. Student financial services
32. Course textbooks
33. Course exams
34. Sandburg and Union ATM machines
35. Enderis Denemark Lounge vending machines
36. Course overheads and slides

The AAA Model: The AAA Model describes this continuum of accessibility. This continuum helps describe types of intervention approaches used to maximize accessibility. It also defines the breadth of the scale to measure the degree of accessibility. Accessibility is the "best of all worlds". This is where an individual has equal access to any service or information like anyone without a disability. In this situation a person with a disability, would not need to obtain any special services, use a separate process, request any special equipment which they do not already own, plan in advance or take additional time. Unfortunately, sometimes the nature of real and severe disabilities compounded by the lag in our engineering abilities prevents us from creating truly accessible situations.

Thus, an effective but second best strategy is accommodation. Accommodation allows a person with a disability to perform all the activities in an environment equal to a person without a disability, but through the use of special services, planning ahead, or by taking additional time.

Examples of an accommodated environment are common and include the need to sign up for sign language interpretation services for a special event, obtaining additional time to take an examination, use of a delivery elevator between a flight of stairs, or the availability of an accommodated restroom in a distant part of the building. While each of these types of interventions achieves accommodation, they do not achieve equal accessibility.

The Access Audit Instruments: Audit instruments were designed to assess the range of accessibility. The 36 audit instruments varied in their documented reliability and validity and the quality of their recommendations. However, most successfully identified points along the spectrum from no accessibility through accommodation to full accessibility and many able to quantify this variance. These Accessibility Audits are being used as a baseline for our campus, to compare improvements over time. The instruments which were used to collect data for identifying the degree of accessibility are considered pilot instruments to be used as idea generators and models for considering accessibility of functions in a campus environment. More than 20 of these Access Audits are available upon request from the research team.

DISCUSSION

The Accessibility Audits at the University of Wisconsin-Milwaukee have increased the awareness of the accessibility needs of a campus of 25,000. The significance of this case study however, is not in the specific recommendations which are made to the campus for improving its accessibility, but in two other results: 1) models for performing Accessibility Audits have been developed as pilot ideas and 2) defining the difference between accommodation and accessibility Vanderheiden, Law and Kelso (2) continue to point out the concept that products and environments should be accessible "right out of the box." This is the overall concept of universal design. What has not been done previously is describing where accommodation and assistive technology tend to fit within the universal design paradigm. Discriminating between the concept of accommodation and accessibility is vital for developing and using measurement instruments that examine the accessibility of products, activities or environments.

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A NEW TRANSDISCIPLINARY COURSE IN ERGONOMICS AND JOB ACCOMMODATION

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ABSTRACT

This paper describes a new transdisciplinary course in ergonomics and job accommodation for undergraduate and graduate students in occupational therapy and engineering. The course is one of six new courses being offered in assistive and rehabilitation technology. The objectives for the course are described, along with the results of the initial course offering. Specific suggestions for future refinement of the course are given.

BACKGROUND

Worksite accommodation is one of four principal practice areas within the field of assistive technology [1]. Previous articles [2-5] have described courses whose objective has been to expose students to this practice area through didactic as well as independent project activities. The typical emphasis of these courses has been job accommodation for individuals with disability. The Certified Professional Ergonomist (CPE) credential [6] has helped establish criteria for development of professional competence in human factors and ergonomics, of which a sub-set is worksite accommodation for persons with a disability. As part of a new six-course curriculum in assistive and rehabilitation technology, we developed a new course in ergonomics and job accommodation. The purpose of this course was to provide students with a background in ergonomics theory and practice guidelines, as well as to facilitate the opportunity for students to evaluate practical situations requiring analysis and intervention for prevention of injury or accommodation of a disability.

OBJECTIVES

Our target student audience was undergraduate and graduate students in occupational therapy and engineering, and our enrollment goal was 15 students. The following content areas were prioritized: (a) surveillance methods for identifying risk factors in the workplace; (b) ergonomic assessment of the worker, task, and environment; (c) strategies to prevent or accommodate injuries to the upper and lower extremities; (d) considerations for selection of hand tools; (e) manual materials handling and the NIOSH lifting equation; (f) functional capacity evaluation (FCE); (g) personal protective equipment (PPE); (h) worker education programs; (i) development of intervention strategies, including engineering controls, work practice controls, and administrative controls; (j) office accommodations, including postural considerations for seating and keyboard selection; (k) accommodation of post-secondary students with disability; (l) epidemiological methods applied to human factors and ergonomics research.

METHODS

Course References

The primary course text [7] provided well-annotated, rigorous treatment of the topic areas listed above. Supplemental readings [8-11] provided additional professional perspectives.

Instructors

Half of the course lectures were provided by the first author, whose background includes degrees in mechanical engineering and OT, and whose work experience includes nine years in the field of assistive technology service delivery. The second author, who has over 20 years of clinical and instructional experience, provided significant support and guidance in curriculum development.

Guest Lecturers

Our expertise was supplemented by several outside lecturers and departmental staff. A mechanical shop technician from our department provided design guidance and fabrication assistance on student projects; a representative of our occupational health and safety department provided lectures on the worker's compensation system, general ergonomics programs, and use of PPE; an OT in private practice conducted a lecture on FCE's; an OT from a local hospital discussed strategies for conducting effective worker education and training programs in industrial settings; and the campus disability services coordinator came to speak about accommodation of post-secondary students.

Assignments

Graded course assignments included: (i) weekly reading assignments from the text and other references; (ii) an individually completed assignment that involved calculation of injury and illness incidence rates and other indicators of risk from an OSHA 200 log; (iii) an individually completed project utilizing the NIOSH lifting equation to analyze the relative risk of a worker at an actual worksite; (iv) a group semester project which entailed students working in groups of 2 or 3 to identify a worker or worksite in need of accommodation, provide assessment of the individual(s) in their work environment, conduct a task analysis and assessment of risk for injury; development of recommendations for change, fabrication of any devices needed, and formal in-class case presentation at the end of the semester; and (v) a final examination featuring case study scenarios requiring short answer and essay responses. Graduate students were also required to complete an article critique of a research paper from the human factors and ergonomics literature. The graduate students were also expected to take a lead role in completion of their group semester project.

DISCUSSION

Outcomes

Ten students completed the course during the Fall 1998 semester -- 9 students were undergraduate occupational therapy students who were taking the course as part of an elective track in vocational rehabilitation. The lone graduate student had a background in industrial design. Four final projects were completed: (i) Three students worked with a local supermarket to develop recommendations for improvement of cashier workstations. This group developed a written survey, collected survey data from over 30 cashiers, analyzed the workstations being used by the cashiers, developed recommendations for improvement of the workstation, and designed and fabricated an adjustable-height stand for supporting plastic bags while bagging; (ii) Two students completed a job analysis and fabrication of a device to aid two workers with visual impairment who are employed at a local manufacturing site; (iii) Three students piloted a pre-vocational skills assessment protocol at a training center for persons with developmental disability; and (iv) Two students worked with a local farmer to help him develop a customized orthotic attachment to his upper extremity prosthesis so that he could better complete two-handed tool operations.

Overall, students enjoyed the course content and assignments. The primary complaint of the undergraduate OT students was that they did not have adequate time in their schedules to invest themselves fully in this course, which is an elective for them.

Future Adjustments

This course unfolded in a fashion that is characteristic of courses that are being taught for the first time - i.e. few things occurred exactly as initially planned, but there were numerous successful elements that offer promise for the future. We were quite pleased with the choice of content, reading materials, assignments, and utilization of guest lecturers. The following changes are planned: (i) We will next offer this course as a three-week intensive seminar during the latter part of Summer '99 . The first two weeks will feature didactic content and initial work on the projects, and the third week will focus exclusively on completion of the projects. (ii) As part of their final projects, the student teams will prepare a poster presentation that summarizes the scope and outcomes of their final projects. The posters will be presented at the beginning of the fall semester to faculty and peers from the respective home departments of students enrolled in the course. This will promote the accomplishments of the individual students, as well as promote awareness of the course among other students and faculty. (iii) The course will be 'marketed' more aggressively to graduate and undergraduate students who are enrolled in industrial or mechanical engineering.

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THE OHIO ASSISTIVE TECHNOLOGY DISTANCE LEARNING PROJECT: A REVIEW OF THE FIRST YEAR

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ABSTRACT

The Ohio Assistive Technology Distance Learning Project (OATDLP) provided graduate level professional development on assistive technology topics in a distance format to 149 participants in the 1997-98 academic year. Fourteen course topics were offered in a schedule designed to meet the registration requests of the participants. Eligible participants were educators, administrators, therapists, and other Ohio school-based personnel who committed to the completion of 5 training modules.

BACKGROUND

In March of 1997, a proposal to provide distance learning opportunities to Ohio's school-based personnel was submitted by ORCLISH to Ohio's Office of Information, Learning and Technology Services (OILTS), an office created by the Ohio Legislature to meet the technology needs of Ohio schools. The project proposed to support the mission of OILTS by: (1) providing professional development for educators using the current technology infrastructure, liservs and web-based training; (2) improving awareness and understanding of the benefits of technology for all students; (3) promoting the inclusion in overall district technology plans of the needs of students with disabilities; (4) increasing the skills and qualifications of district personnel to provide evaluations of students' needs for assistive technology devices and services; (5) increasing the numbers of district personnel to qualified to provide training in assistive technology solutions; and (6) collecting data on the project outcomes. Additional partners in the project included the University of New Mexico's Research Institute for Assistive and Training Technologies (RIATT), SchoolNet, Bowling Green State University (BGSU), the Northwest Ohio Educational Technology Foundation, and the state's Special Education Regional Resource Centers (SERRCs). The project was approved for funding in July 1997. The project funding supported the training and payment of faculty, the learning kit materials provided to the students and the administration of the project. The cost to the students was $100.00 for receipt of one graduate hour of credit, per module.

IMPLEMENTATION

Applications for project participation were sent to the 16 Ohio SERRCs with the request that teams and/or individuals be identified to receive training for their region. The OATDLP faculty was selected, including 4 speech and language pathologists, 1 audiologist, 2 occupational therapists, 1 occupational therapist/engineer, 1 special educator, and 1 licensed school Psychologist/special educator. All faculty members have a minimum of 10 years of experience in assistive technology service provision and are leaders in their area of expertise. To prepare as faculty, each member completed, through the University of New Mexico's RIATT project, the distance learning module(s) that he or she intended to teach in Ohio. RIATT's faculty also provided on-site training to the Ohio faculty in December 1997.

From January 1998 through July 1998, 6 sessions of course modules were offered. Each module was 4 weeks in duration with an additional 7-10 days for faculty to receive and grade the students' final projects and written assignments (mailed to faculty) and to compile and submit grades to BGSU. The course sessions were scheduled with only 0-5 days between sessions. In all, 50 modules were provided and 149 students participated. Of the 149 students who participated in the first year, 96 (64.4%) completed 5 modules as agreed, and 6 of these students completed 6 courses.

All participants received a learning kit developed and licensed for Ohio's use by RIATT. Kit materials included reprints of articles, books, diskettes, CD-ROMs, audiotapes, videotapes, and in some cases, fabrication materials. All kits also included worksheet materials and a competency test on diskette that were to be sent to the faculty at the end of the course. Each virtual class had a dedicated listserv for posting of the weekly assignments and class discussion. The weekly assignments included completion of specified activities from the learning kits (viewing of a videotape, articles, practicing soldering techniques, worksheets, etc.) and questions for the class participants to respond to and discuss online.

The competency test was designed by RIATT to allow students three opportunities to complete the test. Tests ranged from 25 to 50 items depending on the module, and were administered via a diskette provided in the learning kit. The diskette recorded the dates and scores of each trial. For the purposes of the OATDLP, the first assignment for all students was to complete a pre-test (first trial of the test) as a measure of their knowledge prior to the course. Two post-course trials remained at the completion of the course for inclusion in the grade summary.

Student grades were based on participation in the listserv discussion, completion of the weekly online assignments, completion of the worksheet materials, the competency test score and the final project assignment. The majority of the students produced high quality work.

EVALUATION SUMMARY

A summary of the project evaluation has two components: comparison of the pre- and post course test score data, and summary of the course evaluation data acquired via an online questionnaire.

The average number of percentage points gained from pre-test to post-test data was 28.6 for all students across all courses, with an average post-test score of 94.5 points on a 100 point scale. This gain is the equivalent of improving the letter grade from a *D* to an *A*, and represents a substantial improvement in course knowledge.

Course evaluation forms were posted to the listserv at the completion of each course module. Students were asked to complete and return it to the ORCLISH office via mail or email. Although the number of evaluations received was less than desired, responding students indicated that the courses were of value to them in their workplace. Of the respondents, 84% rated the knowledge gained as good or outstanding and 82% rated the usefulness to their job as good or outstanding. Students reported numerous anecdotes about their improved abilities to teach, evaluate, acquire and access new technologies, and implement new processes in their work settings as a result of their participation in the project. They also appreciated the opportunity to interact online with other professionals in similar settings, developing networks within the state for collegial communication and problem solving.

CONCLUSIONS

The response to the courses offered by the OATDLP has been positive. The feedback from students and the data indicate that most of the goals proposed for the project were addressed and that the faculty support was excellent. However, some aspects of the project require change and development.

The course schedule of consecutive sessions from January 1998 through July 1998 with few, if any, days between sessions proved to be very demanding of students and faculty. A number of students withdrew from the project in the spring, citing the schedule as "grueling".

The use of listservs proved to be a challenge early on in the project. Many of the students did not have experience with online communication, email access or computer problem-solving skills prior to their involvement in the project. In the initial weeks their lack of experience was complicated by problems with the reliability of the listserv functions. For students who were computer novices, difficulty with access to the listservs was a frustrating obstacle in their efforts to complete coursework.

FUTURE PLANS

The project has been funded for a second year, which commenced in October 1998, and plans are underway for year three.

The schedule planned for the 1998-99 OATDLP sessions is more practicable. It allows 7 weeks per session: 4 weeks for the course content, 1 week for the student to complete assignments and mail to the faculty, 1 week for the faculty to complete and submit grades and 1 week for an inter-session break. The session offered in October was open to students who participated in the project during the 1997-98 academic year. Registration for the sessions offered from January through July 1999 will be open to new applicants, with funding available to support 75 new students.

The listserv problems have been remedied. Listserv use and access is generally easier and more reliable, and the support staff and faculty are now better prepared to address individual student concerns. However, it is evident to the faculty that the use of listservs alone as the means to communicate on-line with students is limiting.

The project management and faculty plan to incorporate improvements to existing courses via the use of new course materials, message boards with threaded discussion capabilities and web-accessed media. New courses in web-based format and additional faculty positions are planned which will address assistive technology topics not yet covered in the existing modules.

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Quantifying Functional and Outcomes

A TELEMENTRY BASED PRESSURE SENSING SYSTEM

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ABSTRACT

A wireless system is introduced that allows a practitioner to observe in real time the pressures underneath the foot as they occur during walking. The system described includes two modules, a mobile patient unit and a fixed base unit. The patient unit includes two pressure sensing insert pads and a transceiver. The base unit consists of a computer and a transceiver. The two units handshake and send data wirelessly allowing the client freedom of movement from umbilical cords.

INTRODUCTION

Pressure measurements under the foot have been studied since at least 1882 (1). Since then, particular interests have been the study of normal and abnormal gait, assessment of the diabetic foot, changes due to arthritis, surgical procedures, prosthetics design, and sport applications in shoe design. Early pressure measurement systems were bulky and expensive limiting their use to the research laboratory. With the recent development of small, reliable pressure sensors coupled to microprocessors, such equipment is now available for use in the practitioners office (2). These collect information in a time sequence fashion and couple the client to the instrumentation via a multistrand umbilical cord. While representing a major improvement over previous systems they do limit a client's freedom of movement. In addition, the data points are offset in time by the speed of the data input causing system error in comparing pressure distribution across the sole of the foot. With these limitations in mind, a study was undertaken to develop a system which would allow free roaming by the client and capture multiple pressure data points simultaneously from the bottom of both feet.

There were two goals set for this research:

1. data should be sampled for collection at exactly the same instant in time,
2. the system should be wireless.

METHODOLOGY

The system was called a Telemetry Based Pressure Sensing System. It consisted of a portable patient unit and a fixed base unit. Critical to meeting the task was identification of suitable pressure sensors. They needed to be small, tough, reliable and comfortable. The ones chosen are known as Force Sensitive Resistors (FSR) (3). They are very flat and can easily be arranged in different patterns on a shoe insert. In operation, they change resistance as pressure is applied to them. Unknown were the pressure response characteristics of the FSRs. An experiment was designed to determine this. Sixteen pressure measurements were made on a sample of 20 FSRs from 0 to 203.72 pounds per square inch (psi). The results were analyzed using Matlab and then used in designing the system software.

The patient unit consisted of two insole sensor footpads, signal conditioning, a microcontroller and the wireless transceiver (Figure 1). Each footpad, similar to "odor eater pads", incorporated seven FSRs and was connected to the signal conditioning module via a thin ribbon cable. Seven FSRs were chosen as this was sufficient to cover heal, metatarsal, and toe pressures. The signal conditioning module consisted of amplification and capture-and-hold circuits for 14 inputs. The

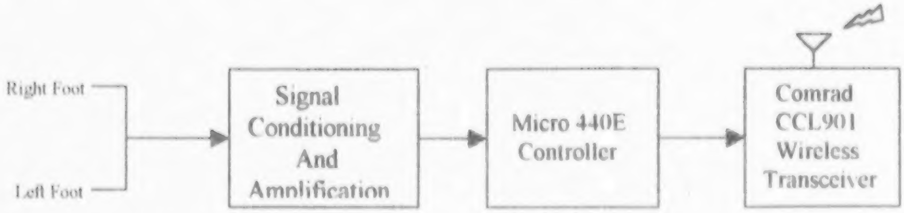

Right Foot
Left Foot
Signal Conditioning And Amplification
Micro 440E Controller
Comrad CCL901 Wireless Transceiver

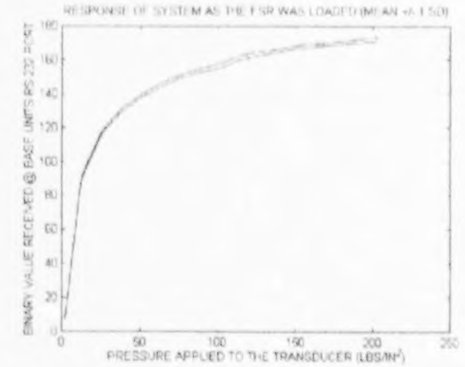
FIGURE 1- BLOCK DIAGRAM OF PATIENT UNIT

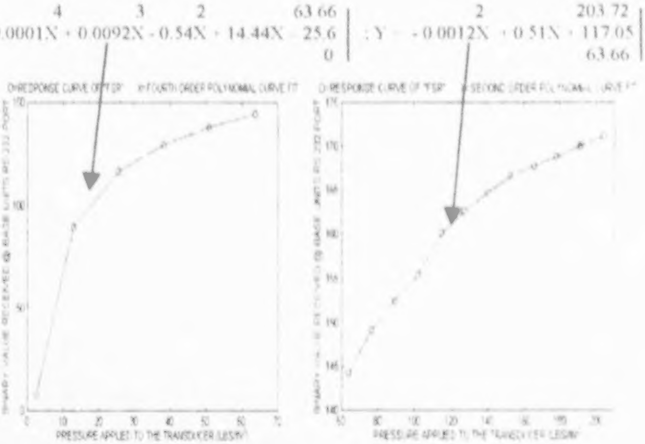
inputs were connected to a high-speed switching/multiplexing network controlled by the microcontroller (4). The microcontroller provided control over when the 14 inputs were captured, then read, and then transmitted to the base unit. The microcontroller's program was written in assembly language. The wireless transceiver provided high speed transmission as an RS232 data stream at 19,200 bps (5). The patient module was battery operated, about the size of a VCR tape cartridge and was worn using a strap around the waist.

The base unit consisted of a transceiver identical to the patient units and a personal computer (PC). The transceiver was connected to the computer via the serial port at 19,200 bps. The computer was a laptop design using an Intel 486 processor. Visual Basic operating under DOS was used to develop the program. The program provided handshaking between the base unit and the patient unit, capture of the data stream, storage of the data, and analysis and presentation of the data on the monitor.

RESULTS

The measurement of the FSR response to pressure was plotted. The resulting mean curve is shown in Figure 2. For use at the base station a polynomial equation was derived from the data. Because the curve exhibited two distinct regions, two equations were produce, one for pressure ranging from 0 to 63.66 psi and the other from 63.66 to 203.72 psi (Figure 3). The results produced a fourth order equation for the first section and a second order equation for the second section. These equations were then used by the base unit program to calculate pressure values from the patient unit data.





$$Y = -0.0001X^4 + 0.0092X^3 - 0.54X^2 + 14.44X + 25.6 \Big|_{0}^{63.66} \; ; Y = -0.0012X^2 + 0.51X + 117.05 \Big|_{63.66}^{203.72}$$

FIGURE 2 – RESPONSE OF SYSTEM AS THE FSR WAS LOADED

FIGURE 3 – FOURTH AND SECOND ORDER POLYNOMIAL CURVE FIT

The system was capable of capturing and transmitting eleven sets of simultaneously data per second as the subject walked on level surfaces or stairs. It was found that reliable data could be recorded up to 75 feet from the base unit. At the base unit the data was provided in real-time for both feet as histograms (Figure 4).

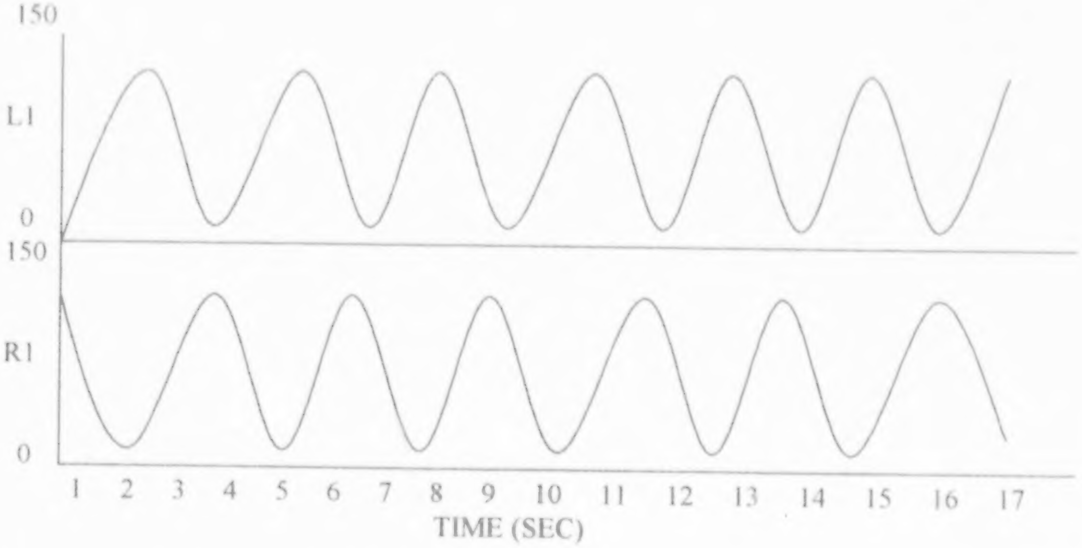


FIGURE 4 – 2 POINT COMPARISION SCREEN

DISCUSSION

The goals for this project were achieved. The overall system operated well performing eleven simultaneous sample sets per second on both feet. The system maintained a satisfactory transmission link within a 75-foot radius of the base unit. This provided for real-time free-ranging pressure measurements. The FSRs were tested for pressures up to 203.72 psi and allowed observation of pressures under the foot as they occurred in real time. The data was also stored by the base unit for addition review and analysis. The insole pressure pads proved easy to fabricate, comfortable to wear, tough, and provided dynamic measurements.

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UPPER EXTREMITY MUSCLE FATIGUE SECONDARY TO COMPUTER USE

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ABSTRACT

Cumulative trauma disorders have increased more than 30% in the years 1981-1991, now accounting for more than 50% of all work related injuries in the United States.[1] Many cumulative trauma disorders are believed to occur secondary to prolonged computer use.[2] A repeated-measures design was used to assess 22 volunteer subjects who keyboarded for one hour on a computer. The muscle strength of the shoulder group, elbow, and wrist was measured bilaterally by a mechanical, hand-held muscle tester (the Nicholas dynamometer). The measurements were taken at baseline (before computer keyboarding), ten minutes after keyboarding, and one hour into computer keyboarding. Anaylsis using a one-way ANOVA demonstrated a significant difference between the eight muscle groups tested. After 60 minutes, the wrist group was the muscle group that fatigued most significantly; and among the four muscles of the wrist, the wrist flexors were the muscles that fatigued most significantly. Finger flexion muscle activity during keyboarding was not tested.

BACKGROUND

In 1988, more than 80% of the reported 240,900 new cases of occupational illness of U.S. workers were cumulative trauma disorders.[3] These disorders are reaching epidemic proportions and are now ranked second in research priority by the National Institute of Occupational Safety and Health.[4] The human cost, and the cost to business, insurance companies, and worker's compensation has been enormous.

Many symptoms are associated with computer use, such as eye strain, neck pain, shoulder pain, carpal tunnel syndrome and wrist pain.[5-7]

Research has demonstrated that fatigued muscles have an increased factor for injury, fatigue being defined as a reduction in muscle strength.[5] Jackson cited the use of the dynamometer for muscle strength testing for work analysis, as a reasonable way to identify workers who would be at higher risk of overexertion injury.[8] In this study, upper extremity endurance was tested with a dynamometer to determine which muscles fatigued first.

RESEARCH QUESTION(S)

This study evaluated which muscle groups in the upper extremity fatigued the fastest after computer use of one hour.

METHOD

Sample

Twenty-two volunteers who were asymptomatic for repetitive motion injury or pain in the upper extremities at the time of the study, and who had not been treated in the past year by a doctor or therapist for repetitive motion injury. Sixteen subjects were female and six subjects were male. The subjects were 18 years of age or older.

MUSCLE FATIGUE

Procedure

During testing, each subject was seated in a straight back chair with the wrist and elbow resting on the table as the measurements for the elbow and wrist were taken. The arm was positioned in the air with the shoulder at 90 degrees, while the shoulder was measured for flexion and abduction.

All muscle testing positions were measured according to the Kendall protocol.[9] The Nicholas Manual Muscle test device was pressed lightly against the subject's skin over the desired muscle group to be tested to record the digital muscle measurement. Muscle strength was tested before the subject began computer keyboarding (as a baseline), after ten minutes of keyboarding (warm-up), and after 60 minutes. During this study, no stress was placed on the volunteer subjects as they were asked to keyboard at their own pace, with no deadline or expected output to be produced from their keyboarding.

The data was collected on the digital read-out of the Nicholas Manual Muscle Tester. The data were then interpreted statistically by computer using t-tests, two way ANOVA (Analysis of Variance) with repeated measures, a Post hoc Analysis and one-way ANOVA.

The level of significance for all statistical tests were alpha=0.05. All statistical calculations were performed using the SAS statistical software package (SAS Statistical Software 6.08, 1991) and Excel 4.0 (Excel 4.0, 1993, Microsoft).

RESULTS

A significant difference was measured among some of the eight individual muscles and the three muscle groups, the shoulder, elbow, and wrist. After 60 minutes, the wrist group was the muscle group that fatigued most significantly, F(1)=4.79, p=0.300, and among the four wrist muscles, the wrist flexors (WF) were the muscles that fatigued most significantly. The elbow group fatigued the least, F(1)=6.78, p=0.100, and the elbow extensors fatigued the least among the entire group, F(1)=4.21, p=0.0416.

The wrist flexors showed significantly greater fatigue after ten minutes of computer work than after 60 minutes of computer work. The mean of the wrist flexors at baseline was 7.4, after ten minutes was 5.24, and after sixty minutes was 4.71.

DISCUSSION

All the wrist musculature demonstrated some fatigue, and the wrist flexors were the muscles that fatigued first, and therefore, were the most affected (Table 1). In an activity analysis of computer keyboarding by the authors, it was noted that wrist extension and finger flexion appeared to be the primary movers when keyboarding. Wrist flexors appeared to stabilize the wrist during keyboarding. Additionally, minimal wrist flexion was elicited when reaching to the keys above the home row.

Table 1: Descriptive statistics for muscle strength (average of left and right muscles) by time (standard deviation, top; mean, bottom).

Muscle	**Standard Deviation**		
	Baseline	10 Minutes	60 Minutes
SA	5.77	5.43	5.37
SF	5.23	5.46	5.65
EF	4.44	2.53	2.92
EE	5.36	4.41	4.07
WF	4.00	2.74	2.32
WE	3.82	3.22	2.20

MUSCLE FATIGUE

Muscle	Mean		
	Baseline	10 Minutes	60 Minutes
SA	12.83	11.50	10.33
SF	13.84	12.64	11.50
EF	10.79	9.74	8.33
EE	11.04	10.23	9.96
WF	7.41	5.24	4.71
WE	6.58	5.35	4.44

SA: shoulder abduction; SF: shoulder flexion; EF: elbow flexion; EE: elbow extension; WF: wrist flexion; WE: wrist extension.

CONCLUSION

The results of this study suggest that the wrist flexor muscle group was the first group to fatigue after prolonged computer keyboarding. The wrist flexor muscle group demonstrated greater fatigue after ten minutes of computer work than at 60 minutes of computer work. The elbow group fatigued the least of all muscle groups tested. Shoulder fatigue did not demonstrate statistical significance.

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IMAGING CHOICES FOR MEASURING MUSCLE THICKNESS

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ABSTRACT

The accuracy and reproducibility of muscle thickness measurements obtained by ultrasound methods were compared to those obtained by magnetic resonance imaging or computer-aided tomography in live human subjects and porcine cadavers. Results show that ultrasound measurements correlate well with magnetic resonance imaging measurements and that repeated measurements with ultrasound are consistent. Because ultrasound is an inexpensive and non-invasive method of imaging, it should be considered a method of choice for muscle thickness measurements in many experimental and clinical situations.

BACKGROUND

Muscle thickness is used commonly as an index to estimate size and force-developing capabilities of muscles. However, common clinical approaches, such as measurement of limb girth, do not always give reproducible or accurate results because the measured part often contains numerous constituents in addition to the muscle of interest (e.g., fat, additional muscles and varying amounts of accumulated fluid) (1). More accuracy can be obtained by using magnetic resonance imaging (MRI) or computer-aided tomography (CT) (2, 3), but these approaches are expensive and contraindicated for certain types of patients (4, 5). We propose to use ultrasound in order to measure the thickness of shoulder muscles in hemiplegic stroke survivors who are undergoing treatment for muscle atrophy using implantable microstimulators (6). However, it is unclear whether ultrasound scans will be sufficiently clear and reproducible to provide accurate muscle-thickness measurements (7).

RESEARCH QUESTIONS

We asked three questions. First, how variable are muscle-thickness measurements made from ultrasound images compared to those obtained using magnetic resonance (MR) or CT scans? Second, what is the intra-observer variation for multiple ultrasound measurements of the same muscle? And third, how are ultrasound, MR, and CT images affected by the intramuscular presence of microstimulators?

METHOD

The thicknesses of deltoid and supraspinatus muscles were determined in six human subjects using ultrasound and MRI. Each subject was positioned prone with the arms held straight, in a neutral position, along the torso. The skin overlying the deltoid and supraspinatus was marked bilaterally at 4 locations with ink and with 8-10 mm diameter metal disks attached using a skin adhesive. Ultrasound measurements were obtained by holding an ultrasound probe perpendicularly to the skin surface and perpendicular to the long axis of the muscle at the locations of the markers; thickness of the muscle was measured beneath each metal marker using the electronic calipers of the ultrasound. The sequence of muscle measurements was then repeated twice to yield a total of 3 values at each location. The metal markers were then replaced by oil capsules and the subject was repositioned in the same prone posture for the MR scans. MR scans were made perpendicular to the skin at the site of each oil capsule. Muscle-thickness measurements were made with Vernier calipers. One set of MR measurements was made. To compare results on muscles with implanted devices, ultrasound, MR and CT scans at 1 cm intervals were made post-mortem on porcine hindquarters in which gluteus maximus had been implanted with two to six microstimulators.

RESULTS

Ultrasound measurements from human subjects differed from their MRI values by a mean of 1.3 mm (6.2 %) (s.d. 1.1 mm; range, -2.9 to 4.7 mm) (Fig. 1A). The larger differences often appeared to be due to differences in registration between sampled sites from ultrasound and MR images. Values obtained by repeating measurements in the same location using ultrasound differed by up to 5.2 mm, with a range of standard deviations of 0.1-2.7 mm for thickness measurements between 12.3 and 47.6 mm. Important contributing factors to differences were slight variations in the angle of the ultrasound probe with respect to the skin and variation in pressure applied over the muscle, which can flatten the muscle by up to 50% if extreme pressure is applied.

In porcine muscles, MRI and CT measurements at the same location were very similar (mean of absolute differences: 1.5 mm; 3.1%) (Fig. 1B). Implanted microstimulators could be identified with all three methods (Fig. 2). They were hardest to visualize using ultrasound because they appeared as a thin white line only. On CT scans, they were clearly apparent and had small bright lines radiating from the electrodes. On MR images, the shadowing was pronounced and formed a halo up to 2 cm deep around the device.

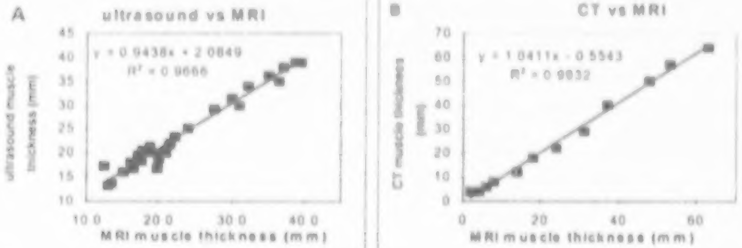

Figure 1: A. Muscle thickness measurements on human muscles using ultrasound and MRI; B. Muscle-thickness measurements on porcine muscles using CT and MRI.

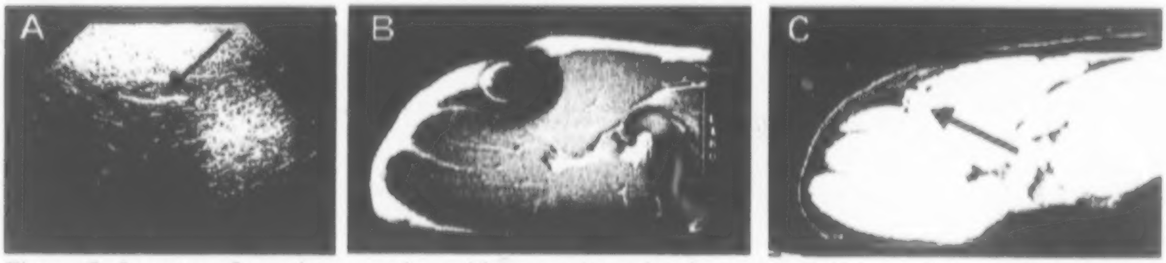

Figure 2: Images of porcine muscles with one microstimulator - (arrows pointing on A and C) A. ultrasound; B. MR; C. CT. On all images the microstimulator is approximately 7 mm into the muscle.

DISCUSSION

The small differences typically found between values of muscle thickness using ultrasound and MRI suggest that ultrasound provides a useful method for measuring shoulder-muscle thickness, especially in situations where cost, availability of equipment, or the presence of contraindicating factors restricts the use of repeated MR or CT scans. The occasional large differences that were seen in this study were often thought to be due to variation in the planes of MR and ultrasound images, rather than limitations or distortions of the images themselves. Nevertheless, muscle borders can sometimes be hard to discern in ultrasound images, and errors will occur if other fibrous structures or planes are mistaken for muscle borders. Further, ultrasound imaging may be inadequate if the muscles to be measured are located deeply or shadowed by overlying bone. MR and CT scans provided almost identical muscle-thickness values. However, MR images in particular were marred by large shadow-like artifacts around implanted devices. In a small muscle, these distortions might obscure the muscle boundaries and thus interfere with accurate muscle-thickness measurements.

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THE EFFECTS OF JOINT LOADING ON PASSIVE MOMENT MEASUREMENTS

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ABSTRACT

In this study, the aim was to measure the passive moment at the ankle under different loading conditions. For the experiment, the ankle was rotated at 10, 50, and 100 deg/s and the load on the ankle was varied from 0-15 kg. The results showed that applying a load affected the hysteresis of the passive moment response. The change in hysteresis suggests that friction within the joint may be increased due to a larger contact force between the articular surfaces. However, the change in the moment response was so minimal further analysis must be performed to quantify the change.

INTRODUCTION

The passive moments at the lower extremity joints have been studied by many previous researchers (Goddard et al., 1969; Such et al., 1975; Weiss et al., 1986). Several studies (Mansour and Audu, 1988; Riener and Edrich, 1997; Vrahas et al., 1990; Yoon and Mansour, 1982) have measured passive moments to determine their relative contribution to the total moments needed during various activities, such as gait or sit-to-stand transfers. In these studies however, measurements were made under conditions where the joint loading was not representative of the loading that would be experienced during the activity of interest. The effects of joint loading were assumed to be negligible although this assumption was made with little supporting evidence.

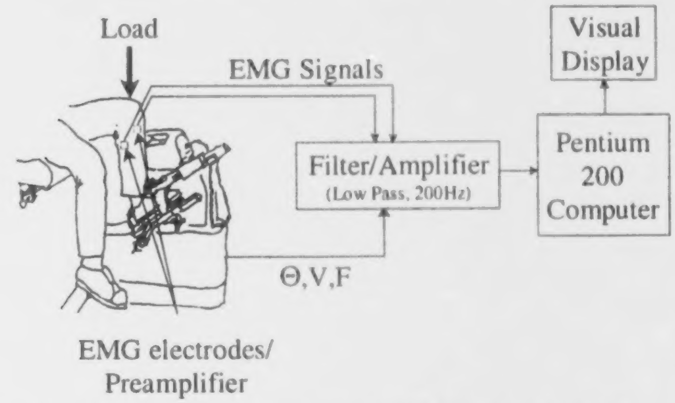

Figure 1. Experimental setup used to test the effects of joint loading

Consequently in this study experiments were conducted at the ankle to investigate how passive moments changed with joint load. By examining this relationship we hoped to determine whether or not the influence of joint loading could be assumed to be negligible.

METHODS

We measured the passive moment at the ankle of one representative healthy subject. The subject was a male aged 35 years, weighing 83kg (183lbs) with a height of 178cm (5' 10"). A KinCom 500H muscle testing system was utilized to measure the moment as the ankle was passively rotated at a constant velocity. The velocities used included 10, 50, and 100deg/s. The subject was placed in the measuring apparatus with the ankle joint aligned with the center of

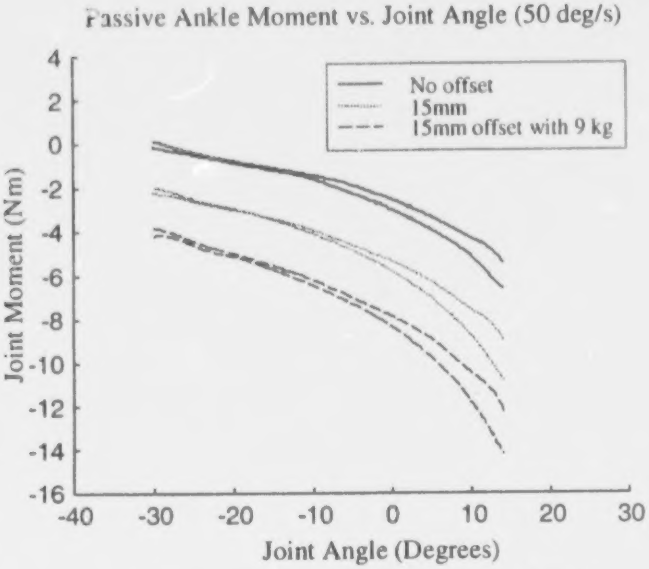

Figure 2. Effect of misaligning the center of rotation

rotation of the machine and the shank positioned vertically. To obtain this position the subject's knee was placed at 105 degrees of flexion. To simulate the various ankle joint loading conditions, masses of 0, 3, 9, and 15 kg were placed on top of the knee (Figure 1). Because of the configuration of the subject, the force of the weight was transmitted to the ankle. The choice of weights corresponds to approximately 0, 10, 30, and 40% of the load the knee would experience during standing. Before measurements were made the ankle joint was also preconditioned by rotating it at 100 deg/s for 20 cycles.

Determining an effective center of rotation for the ankle was a difficult task. Consequently, a set of tests was performed with the ankle misaligned from the designated center. This variation allowed for a better determination of the true center of rotation. Subsequently, calculations were made to correct for errors due to misalignment.

RESULTS

In Figure 2 the results from the 50 deg/s test are shown. In this diagram, angles greater than zero denote dorsiflexion and angles less than zero denote plantarflexion. The upper curve of each trace represents a movement from dorsiflexion to plantarflexion. The lower curves represent movement in the reverse direction. From the figure a vertical displacement between the curves can be noted. Using the 'No offset' curve as a baseline, the '15mm offset' curve is shifted due to the misalignment of the center of rotation of the ankle. Adding a load to the misaligned joint causes a further vertical displacement of the trace. Using these results, corrections for a misaligned joint could be made.

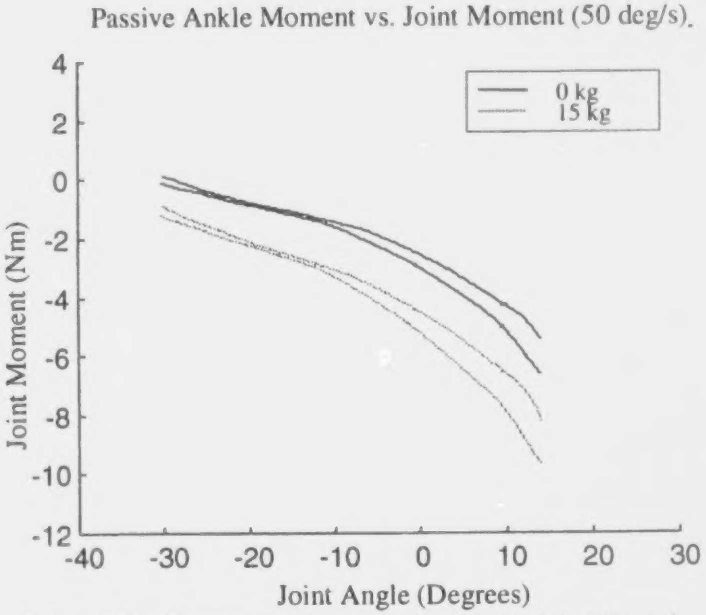

Figure 3. Passive moment measurement in the unloaded and loaded conditions

The results of Figure 3 show the change in the passive moment response due to joint loading. It appears that joint loading leads to an almost imperceptible increase in the amount of hysteresis of the response. Velocity appeared not to influence the effects of joint loading.

DISCUSSION

These preliminary results suggest that joint loading can have an effect on passive moment measurements. It is hypothesized that joint loading increases the normal force between the articular surfaces of the joint. As a result of the increased normal force a larger frictional force is produced. However although joint loading appeared to affect the passive moment measurement, the change was only minimal. Therefore these results indicate that when measuring passive moments and developing passive moment models, joint loading does not need to be a concern.

In this study, the effects of joint loading on the passive moment measured at the ankle were examined. The results show a qualitative change in the amount of hysteresis as a result of the added weight. However, a quantitative description of this observation still needs to be developed. Further investigations including more subjects are planned to determine if joint loading effects are statistical significance of these passive moment results.

ACKNOWLEDGEMENT

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A DIRECT BRAIN CONNECTION FOR CURSOR CONTROL

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ABSTRACT

A neurotrophic cortical electrode has been developed and is being tested in human subjects. This study investigates the level of control over the firing of neural action potentials that the subject can achieve in order to use them to control the computer cursor. A training regime is presented and the access method is tested in the Windows '95 ™ environment to perform text entry and voice output for communication. To date, the subject has achieved some control over the firing rates and is able to type his name using the neural signal.

BACKGROUND

A direct brain interface can provide a control site for people who have severe disabilities, for instance, those in the later stages of Amyotrophic Lateral Sclerosis (ALS) or those who have had brain stem stroke. Their brains are still active and aware, but their bodies prevent them from communicating their needs and thoughts. Several signals for computer-brain interfaces are being researched including electroencephalogram and electrocorticogram (1,6). One drawback of these techniques is their low signal resolution. The user can have an on/off control, and even a step function in one dimension. However, the amount of information available from the signal is not enough for a direct means of access.

A direct brain connection can potentially provide enough information for a direct access method. Neurons produce action potentials (APs) and the neural firing rate changes with cognitive efforts. That change in firing can be translated into control input for a computer. Tonic firing of the AP (firing at a constant frequency) can be used to extract a position value for a computer cursor. Thus, different cursor positions can be obtained by changing the firing level of the AP. Phasic firing of the AP (bursts where the rate increases from one value to another) can be used to extract a velocity value for the cursor. The bigger the change in frequency of the firing, the faster the cursor will travel. Thus, two APs can potentially control the X and Y position of the cursor on a display. A Neurotrophic electrode has been developed for implantation into the brain (2). Primate studies have proven that APs can be recorded from one electrode with each action potential having distinct shape and behavior correlation (3,4). The first human study, with a woman who had ALS, presented the following results: the surgical implant procedure is safe, the signal is stable and reliable, control of multi-unit firing activity using cognitive efforts is achievable, and individual action potentials can be extracted from the signal data (5). The research team is presently performing another human study with a volunteer, JR, who had a brain stem stroke which left him completely paralyzed and ventilator dependent.

RESEARCH QUESTION

Can someone who uses the Neurotrophic electrode learn to control firing rates of APs well enough for direct control of a computer cursor? If direct control is not possible, then how much information can be extracted from the AP to improve the selection method beyond that of an on/off signal?

METHOD

The electrode structure, wireless transmission circuitry, signal processing and archival equipment are shown in Figure 1 and described in detail elsewhere (2,3).

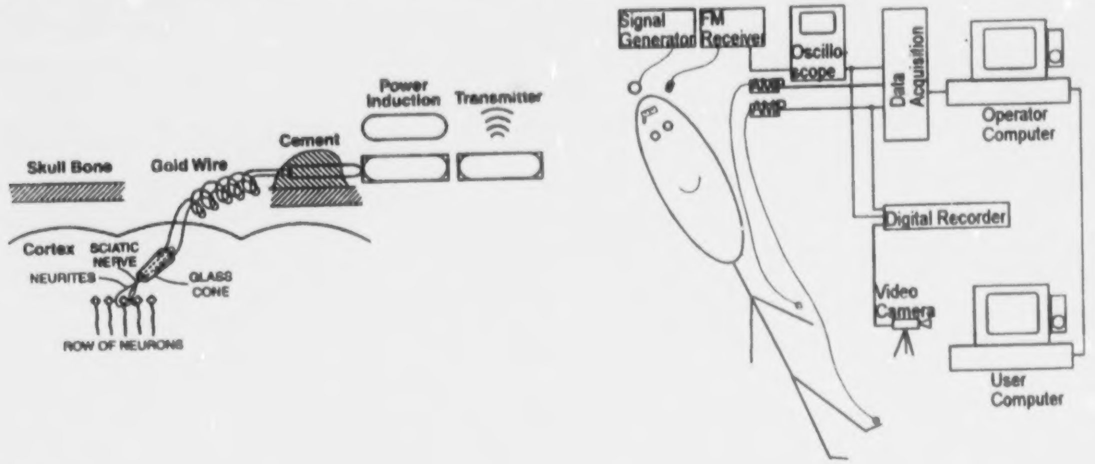

Figure 1

Recorded waveshapes above an operator specified threshold are analyzed according to seven parameters in order to separate APs (3). When an AP occurs that meets the criteria an auditory tone is sounded and that occurrence is indicated to the user computer.

The program to train the user to control the APs consists of vertical bargraphs of different colors. The operator varies target number, position, and size in order to challenge the user. Both tonic and phasic firing of the AP must be trained, thus, the height of the bar graph can represent the AP firing rate or the change in firing rate. The user visualizes the performance of movements which produce the required audio and visual feedback.

After gaining some control of the APs, the user graduates to the Windows '95 user interface, where a custom mouse driver translates the number of occurrences of APs into cursor position and velocity in the vertical and horizontal direction, as well as a click. Tasks that will be trained and analyzed are text entry, voice output for communication, telephone access, and environment controls.

RESULTS

JR underwent surgery to implant the electrode in March, 1998. The electrode began to display neural activity after the expected time required for neurons to grow into the electrode cone. After nine months of 3-4 sessions per week, JR has gained some control of the APs. Quantitative analysis is underway. However, some qualitative observations can be made.

JR has not been able to control two APs independently. He has regained some muscle function, first, the abductor hallucis in his left foot and later the brachioradialis in his left arm. That extra functionality is used for accessing Windows; the neural signal induces cursor movement in the X direction, the foot electromyograph (EMG) is used for control in the Y direction and the arm EMG activates a mouse click. All EMG waveshapes above an operator determined threshold are accepted and the number of occurrences are passed along with the neural occurrences to the user computer.

JR is presently utilizing only phasic firing to drive the cursor. The mouse driver was

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modified so that the cursor will move to the right, driven by the neural signal, with a speed according to how fast JR produces changes in AP firing frequency. Thus, when the cursor is far from his target, JR produces many AP changes to increase cursor speed, and when it is close to the target, he moves it more slowly. Occasionally, there is a burst of neural activity, possibly due to general tension, when he gets near to the target which causes him to overshoot it.

So far, JR has used WiViK ™ for text entry and WiVox ™ for voice feedback. When using the full keyboard with word prediction JR obtained too many unwanted selections. However, JR is more successful with the simple keyboard layout with no space between keys. He has produced his name with only one error in less than 5 minutes.

DISCUSSION

Although not at the direct access level, the signals JR is using are proportional, which is an improvement over scanning access. More training is required, on a daily basis, in order to have greater control over the APs, and to understand what cognitive efforts cause unwanted firings.

JR's progress has been impeded in many ways. Firstly, training was interrupted when JR went into intensive care with a respiratory illness. The time away from daily training decreased the "memory" of the neurons. Secondly, training session length is limited to less than 2 hours. After that, the APs disappear as JR tires. Finally, the action that he must visualize in order to produce the desired effect has changed over time. Initially, imagining his arm moving produced APs and now, moving his eyes produces stronger signals. Since his face has had the greatest sensory and motor activity for the last 9 months, perhaps the areas of the brain that were used for the arm have been subsumed by the face. There is a very small EMG signal developing on JR's right arm. If it increases to a usable level, then it will be easier for JR to use three EMG signals to control the cursor movements, and the neural signal will be monitored to see how it reacts during EMG activity.

There are immediate plans for software modifications to allow more operator adjustability, for example, for time delay and cursor start position. Future work involves development of the next generation of electrode circuitry and improvements to the software interface.

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USE OF ADVANCED COMPOSITES FOR ANKLE-FOOT BRACING FOR CHILDREN WITH MYELOMENINGOCELE

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ABSTRACT

The aim of this project is to improve ankle-foot bracing design for the myelomeningocele child by exploring the use of advanced pre-impregnated (prepreg) composite materials used in the aerospace industry. Orthotic support for this population has always been difficult, but it is important for the physiological and social development of the child. This project aims to develop and investigate a next-generation fabrication technique using a novel composite formulation that has the potential to overcome several current problems of ankle-foot bracing. The results of this work may lead to stronger, stiffer and lighter braces for the wearer, and improve methods of brace fitting, fabrication and delivery.

BACKGROUND

While the industry-standard material for lower-extremity custom-made ankle-foot orthoses (AFO) is thermoplastics (Figure 1a), its fabrication process is labor-intensive (1). The polypropylene braces are often not stiff enough to adequately constrain range of motion. Metal bracing is stronger, but is sometimes too heavy and cumbersome, and requires considerable fabrication and modification time. Alternatively, composites currently appear promising, but the present state-of-the-art technique for using carbon fiber is a wet lay-up lamination procedure. Such a procedure is toxic, timely, and expensive and the resulting braces are bulky and are unable to be post-formed (Figure 1b) (2).

This research is concerned with exploring means of bringing advanced composites to the forefront of orthotics technology in the same way that it has brought benefits to the aerospace and sports industries. This project aims to explore the utilization of advanced composites in (i) providing stronger, stiffer and lighter ankle-foot orthoses for the wearer and (ii) improving methods of AFO fabrication, fitting and delivery. In doing so, it is hoped that achieving these goals will overcome several current problems of ankle-foot bracing.

Figure 1: State-of-the-art Ankle-Foot Orthoses (AFOs). (a) [left] Posterior Polypropylene AFO with Single Axis Hinges, (b) [right] Posterior Wet Lay-up Composite AFO

METHODOLOGY

A unique fiber epoxy pre-impregnated (prepreg) fiber cloth has been used to fabricate a number of AFO designs. The use of this room temperature-storable composite prepreg permits a lightweight AFO to be custom-manufactured over a positive cast mold. The prepreg cloth is cut and placed over the cast, in accordance with the desired shape. Carbon fiber plain-weave (Figure 2a) and 30° braided tube (Figure 2b) are used for the lay-up on the cast. The braid is used primarily as a structural support, while the plain weave provides support between the braided foundation. Section thickness is achieved by placing more plys over areas where needed. The tackiness of the prepreg makes self-adhesion possible, with no noticeable odor. The cast along with the prepreg lay-up is wrapped in shrink tape (Figure 2c) before being placed in a high-temperature nylon vacuum bag. The vacuum line is fed through an opening in a laboratory convection oven. The oven controller is then programmed and cured at 310°F for one hour under a vacuum of 29 in. Hg (1 ATM).

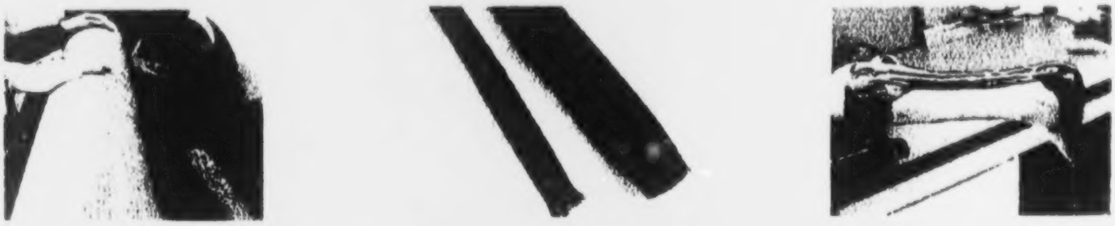

Figure 2: (a) [Left] Carbon Fiber Plain Weave Prepreg Roll, (b) Braided Tube Prepreg and,
(c) Prepreg Lay-up over a Plaster Cast to the Desired Brace Trim

RESULTS

Feasibility & Able-Bodied Subject Testing

Proof-of-concept AFOs were fabricated which demonstrated feasibility. Thereafter, posterior semi-rigid, and posterior rigid AFOs were fabricated and fitted to able-bodied subjects, who tested the braces by conducting their normal work activities (Figure 3a). Anterior (floor-reaction) AFOs were subsequently fabricated due to their large prevalence in myelomeningocele bracing (Figure 3b), and again, were tested with able-bodied subjects. The anterior shell, does not preventing knee hyperextension as adequately as the posterior design. On the contrary, it is often more beneficial for the myelomeningocele children because it prevents knee flexion that is not adequately controlled by their weak quadriceps. All test AFOs have been fabricated with full-length footplates to increase the lever-arm and maximize support during the terminal stance phase of gait, as is the case with AFOs worn by children with myelomeningocele.

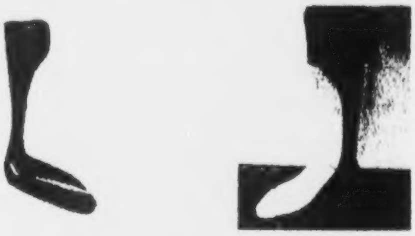

Figure 3: (a) [left] A Prepreg Carbon Epoxy Posterior AFO and, (b) A Prepreg Carbon Epoxy Anterior (Floor-Reaction) AFO

Mechanical Characterization

The design of the AFOs have been facilitated by mechanical characterization of the composites used. Test coupons for tensile, flexure bending and compression characterization have been prepared and tested. One probable area of the full-length foot plate anterior AFO where bending will occur most and cause stress concentrations, is at the forefoot of the brace. This is one area on the AFO design where fractures will most likely occur. To this end, we have begun to explore material properties through testing that may add insight into this potential problem site. Data from the mechanical tests will be presented.

Material handling and Preparation

The Project has undertaken serious consideration for providing the most appropriate working environment in handling and preparation the prepreg materials in fabricating the braces. The laboratory employs appropriate ventilation and dust collection equipment for brace sanding before brace use. Additionally, all investigators are required to use correct eye and respiratory gear when working with or near these materials.

DISCUSSION & FUTURE RESEARCH

Patient Testing

Patient testing has begun recently on children with myelomeningocele with two major myelomeningocele clinics in the Los Angeles area. The children will wear the composite test AFOs for several weeks and provide feedback on fit, function and other aspects of their experience. In addition to subject feedback, clinical observation of gait parameters will be made with the child wearing both his or her existing AFO and the composite AFO for comparative purposes.

Exploring Novel Fabrication Techniques

The investigators have discovered that the curing process of the composite material can be partially-cured under vacuum. This means that after removal of the composite AFO from the mold, the material maintains its shape but can be adjusted and returned to the oven for final curing, with no need under vacuum. The cured part will retain the shape of the adjustment. This advance may result in commercialization of this technique so that modular sized AFOs could be fabricated by the manufacturer in a partially-cured state and sold to the clinician, where it may be stored at room temperature. As needed, the orthotist would then custom-shape and fit a modular AFO directly to the intended patient, without the need for casting or repeat visits by the patient. Overall, the process may allow for rapid delivery of custom-fitted AFOs and in doing so eliminate fabrication time, reduce patient visits, labor costs and overall healthcare costs, while providing lightweight, strong and low-profile braces that may improving mobility for children with myelomeningocele.

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OUTCOME MEASURES IN VISION TECHNOLOGY: AN APPLICATION OF THE CANADIAN OCCUPATIONAL PERFORMANCE MEASURE

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ABSTRACT

The objective of this paper is to demonstrate how a particular outcome measure, the Canadian Occupational Performance Measure (COPM) has been successfully used on a routine basis as part of the Vision Technology Service. Data from 3 clients were presented in single case study format and the pooled results from 12 clients were reported in a second report. Our experience has shown the COPM to be an effective outcome measure for monitoring the impact assistive technology has had on clients' occupational performance and on their satisfaction with this performance. Recommendations for future applications of the COPM to AT are provided.

BACKGROUND

Despite the considerable short and long-term costs for assistive technology (AT) devices and services, consumer demand has increased extremely rapidly since the early 1980s. In recent years, however, a variety of economic factors have made it increasingly difficult to continue to provide a high level of AT support in the absence of evidence supporting its efficacy (1). In concordance with attitudes and values advanced by society at large, health care service delivery is now placing greater weight on professional accountability and personal responsibility in client evaluation and performance monitoring (2).

It has now become essential that AT practitioners, administrators and researchers establish methods for demonstrating that their services are both effective and meaningful. The realization of this economic reality has reinforced the clinician's inherent interest in verifying the efficacy of AT support. The availability of solid outcome measurement tools will enable AT practitioners to determine the cost effectiveness of their services and to gauge the value of providing assistive technologies. Moreover it will facilitate the evaluation of how users perceive the impact AT has on their daily lives (2). There is thus a strong mandate, driven by both the external need to justify AT services and the internal wish of practitioners to provide optimal AT solutions, to develop, test and use outcome measures in a routine manner. Unfortunately, the development and use of AT outcome measures is not a simple matter (3). Existing outcome instruments tend to be narrow in their domain of application. Construct validity is not easy to achieve. There is great variability amongst both the target clinical population and the large variety of existing AT devices and services and considerable time can pass from an initial assessment until realization of functional goals.

OBJECTIVE

The objective of this paper is to demonstrate how a particular outcome measure, the Canadian Occupational Performance Measure (COPM) has been successfully used on a routine basis as part of the Vision Technology Service. The COPM is a valid and reliable measure designed for use by occupational therapists to detect a client's self-perceived change in occupational performance over time (4). It is particularly suited to AT because it focuses on changes in occupational performance before and after equipment intervention, identifies adequacies or failures in both support performance and intervention performance and documents the need for further equipment intervention, support training, environmental changes or re-assessment.

METHOD

The use of the COPM as an outcome measure was incorporated into a proposal for a 'Regional Assessment Centre for Sight Enhancement and Sight Substitution High Technology Devices' presented to the Assistive Devices Program of the Ontario Ministry of Health. The proposal was approved and the Vision Technology Service (VTS) at the University of Toronto's Adaptive Technology Resource Centre (ATRC) commenced its first assessment in November, 1996. The follow-up results from a modified version of the COPM are part of the biannual Quality Assurance (QA) report to the Ministry of Health, along with responses to a Consumer Satisfaction Survey. The objective of using the COPM in the VTS was to obtain client centered outcome data which would document the effectiveness of clinical intervention and provide the funding agency with an indicator of quality assurance.

Incorporated into each assessment is a modified form of the COPM which identifies the needs and problems the client encounters in reading and writing in the three areas of occupational performance: self care, productivity and leisure. The most important problems are selected for scoring and rated by the client for performance and satisfaction. Clients are contacted for follow-up self-rating after they have received their equipment and training. Any issues raised by clients are noted, and they are asked to rate their performance and satisfaction in the problem areas with the use of their new equipment. Results are discussed and any further intervention or cross referrals needed are planned. The results are recorded in the clients' initial assessment file and a copy kept for QA purposes. A change of 2 points out of 10 in the performance or satisfaction rating is considered to be clinically significant. Prior to preparing the biannual QA report, the average change in performance and satisfaction scores for each client are calculated. The mean change for the entire group of available clients is tabulated and presented as a measure of the effectiveness of equipment prescriptions in meeting clients' identified needs.

RESULTS

Data from 3 clients were presented in single case study format in the first two reports, then as increasing numbers of clients were assessed and became experienced in equipment use, results from 12 clients were reported in the most recent report. One of the first cases, reported here as an example of the single case format, involved a client who was authorized for a CCTV(Closed Circuit TV) and was given recommendations for modifications to his parent's home computer system and a CCTV at school. This client identified three problems. For the first problem, sustained reading of books and textbooks, a change in performance with CCTV showed an improvement of 5 points on the 10-point scale and a change in satisfaction with CCTV showed an improvement of 3 points on the 10-point scale. No changes in performance and satisfaction were noted in the other two identified problems of difficulty reading handwriting and fatigue in handwriting. The follow-up discussion revealed that the family had set up the CCTV on a surface too high for the client for handwriting and that they would adjust this. VTS staff initiated a referral for school based occupational therapy to address the handwriting concerns with the school CCTV.

It is also useful to pool COPM data obtained from larger numbers of clients. In our clinic, data were collected from 12 clients over a six month period. The mean improvement in performance rating was 4.8, with a range of 8 to 2.6 among those who had completed their training. The mean satisfaction improvement was 5.0, with a range of 9.5 to 1.3. All clients reported significant problems prevented him from completing his training. The same client and one other showed improvement in satisfaction with the performance of the assistive technology, but not high enough to be considered clinically significant. In discussion with the clients we found that more training was desired by a number of individuals and that some had had difficulty obtaining funding for their portion of the equipment costs.

DISCUSSION

The model used at the Vision Technology Service is to compare clients' COPM self ratings in performance and satisfaction in writing and reading needs after they have received their equipment and training to their self ratings at the time of initial assessment. We have selected this tool because it is sensitive to functional changes that can be brought about by assistive technology and because it focuses on performance issues of importance to the client. Indeed, on a number of occasions the COPM has served to focus the assessment and has helped to identify problems that clients would likely not have otherwise raised as issues. Finally, the COPM provides numeric confirmation of effective equipment use by clients and effective equipment recommendations made by clinicians, data which has been positively received by provincial and private funding agencies.

Our experience has shown the COPM to be an effective outcome measure for monitoring the impact assistive technology has had on clients' occupational performance and on their satisfaction with this performance. The measure is relatively easy to administer by the trained clinician and can be readily incorporated into a typical clinical assessment. It does necessitate that clinicians find the time and human resources to schedule periodic re-evaluation since follow-up data are essential for comparison purposes. We see this in a positive light; the COPM encourages the clinician to systematically incorporate follow-up evaluation (of great importance in AT service delivery) as part of the clinical routine.

In order to further improve the provision of service to our clients we plan to:

- continue to collect initial and follow-up COPM data from all AT clients. This will add considerably to the existing data pool enabling further comparisons amongst clients of differing characteristics (e.g., age, pathology, AT needs, identified problems);
- compare COPM results with other AT outcome measures (e.g, PIADS, QUEST). This will contribute to a better understanding of the value of the different types of information now available to clinicians;
- promote a multi-centre AT-COPM data pool which would serve as a resource for AT centres around the world. This would provide a basis for probing differences in AT services as a function of, for example, clinical population, AT centre structure and cultural background.

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FUNCTIONAL OUTCOMES OF ASSISTIVE TECHNOLOGY FOR ADULTS WITH DEVELOPMENTAL DISABILITIES

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ABSTRACT

A group of 109 adults with developmental disabilities living in institutions with a mandate to transition to the community received AT services and were followed four years post intervention to determine functional status changes with and without AT over time. Results support the beneficial impact of AT on functional status gain or maintenance over time for individuals with severe disabilities who are aging in place, both in nursing homes and in the community.

BACKGROUND

There are over 526,000 adults over the age of 60 with mental retardation and other developmental disabilities in the U.S.[1]. As these individuals age, they experience both disability and age-related issues, including cognitive and communication impairments coupled with decreased sensation, vision, hearing, and mobility. These threats to function may be experienced as early as age 35 for persons with Down Syndrome. As increasing numbers of people with development disabilities live in the community, AT has been increasingly prescribed and legislatively mandated. However, few studies have examined the impact of AT interventions on functional status with adults with development disabilities as they age in place over time in community and institutional settings. An outcome study of 35 adults with cerebral palsy and mental retardation showed that functional screenings and AT services resulted in functional improvements over time [2]. A study of AT use among 67 adults with developmental disabilities found that persons in nursing homes had greater functional limitations in mobility, communication and activities of daily living, and used less AT to address these limitations[3]. This sample was later expanded to 109 people. This paper reports on preliminary functional status changes for this group from initial intake [3] through 4 years post.

RESEARCH QUESTIONS

1. What is the relationship of AT use to functional status at specific points in time (within 1 year of intake, follow-up four years post intervention)?
2. What is the relationship of AT to functional status over time from intake to follow-up?

METHODS

As part of a larger study, a total of 268 adults with developmental disabilities, all of whom were initially living in institutional settings, were followed. Of this number, 109 subjects received AT services through a community-based AT service delivery center. The average age of these subjects was 50.15 (range 22-83; S.D., 13.10); gender: 48% men, 52 women; and living situation: 53.2% in community (family, CILAs, other) and 46.8% in institutions (nursing homes, etc.). Functional status and AT use were assessed at Time 1 (within 1 year of receiving initial AT services) and Time 2 (an average 4 years post intervention) using an adapted version of OT FACT, a functional assessment instrument [4]. A total of 32 functional tasks reflecting basic and instrumental activities of daily living were assessed using a 3-point scale: independent, requires some assistance, dependent. Each subject was rated under two conditions: 1) without AT (person rating), and 2) with AT (environment adjusted rating) at Time 1 and 2.

RESULTS

Rasch analysis was used to transform ordinal raw scores from the 3 point scale into equal interval linear measures, referred to as logits (log units)[5]. 95% confidence intervals, marked as dashed lines on figures, were computed to determine significant differences across conditions (with AT and without AT), and over time (from Time 1 to Time 2). Figure 1 shows comparisons of subjects' functional performance at Time 1 with and without AT. The majority of subjects exhibited improved functional performance with AT as compared to without AT (51/89; 57.3%), 36.1% (33/89) showed no change, and 5.6% (5/89) had worse performance when AT was used (20 subjects had missing data and were not included).

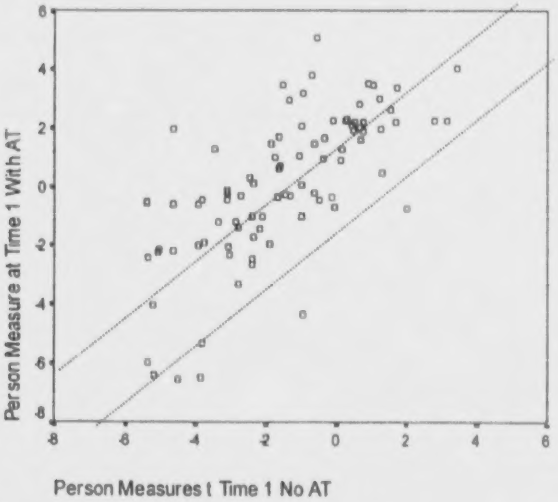

Figure 1: Functional status at Time 1 with and without AT.

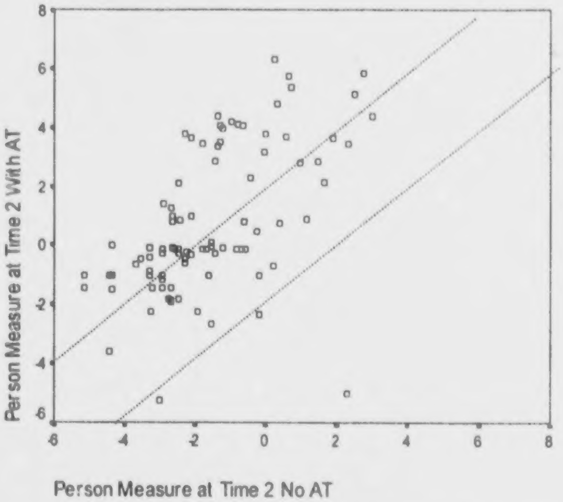

Figure 2: Functional Status at Time 2 with and without AT.

Figure 3 shows comparisons of subjects' functional performance with AT at Time 1 and Time 2. 24.7% had better performance at Time 2, 65.4% did not change, and 9.9% had worse performance at Time 2 (n=28 had missing data; n=81 analyzed). When compared to functional status without AT at Time and Time 2, 14.0% had better performance at Time 2, 58.9% did not change, and 27.1% had worse performance at Time 2 (n=2 had missing data; n=107 analyzed) (see Figure 4).

DISCUSSION

Preliminary analysis demonstrates the impact of AT on function for this sample of 109 individuals with developmental disabilities, all of who began the study in nursing home or other institutions, at each point in time, and across 4 years post intervention. The majority of subjects either improved or maintained functional status with AT (only 9.9% had worse performance with AT versus 27.1% without AT over time). The results also provide evidence to funders regarding outcomes of later life AT interventions for persons with developmental disabilities as they age in place.

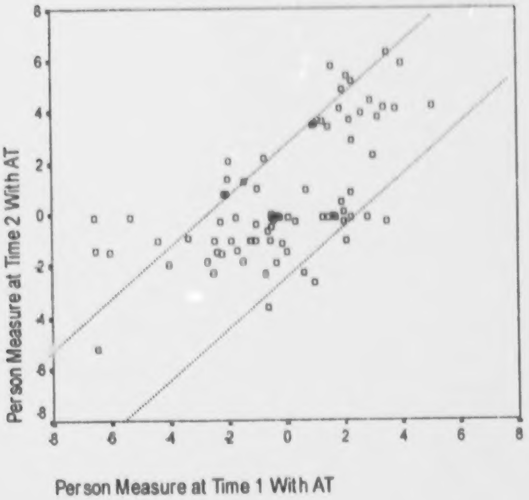

Figure 3: Functional status at Time 1 & 2 with AT

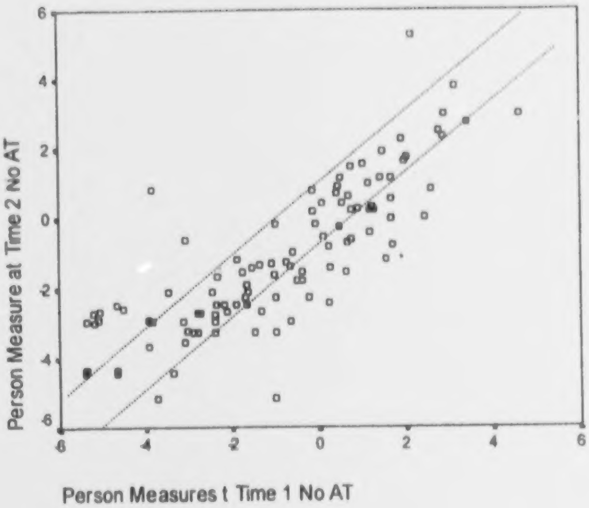

Figure 4: Functional status at Time 1 & 2 without AT.

Future analysis will examine the differences between subjects who remained in the nursing homes versus those who transitioned to the community, focusing on which types of AT (e.g., seating, communication) impacted most upon overall functional status as well as specific activity performance (e.g., eating, cooking). Rasch analysis also will be used to examine the hierarchy of difficulty of the OT FACT items and the sensitivity of the items for this population and to AT.

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EFFECTS OF THE TRANSITION TO POWERED MOBILITY ON OCCUPATIONAL PERFORMANCE

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ABSTRACT

Persons with mobility impairments who use wheelchairs view the change from manual to power mobility device (PMD) in negative terms—as a sign that their condition is worsening or that they are losing function. Using a structured interview format, this study compares changes in occupational performance, life roles and quality of life of eight people with various diagnoses who had previously used manual wheelchairs but changed to PMDs. The Occupational Performance History Interview and the Psychosocial Impact of Assistive Device Scale were used to measure the effect of the PMD. The results indicate that PMDs are associated with a significant increase in adaptive performance in everyday life.

BACKGROUND

Many individuals who use wheeled mobility devices rely on them to move independently in their surroundings, to engage in meaningful activities and to enact the roles of every day life. A mobility device makes a pivotal contribution to a person's quality of life when it both meets an individual's needs and matches their environment (1). According to Warren (2), moving around under one's own volition is the foundation for a lifestyle of independence and self-initiated behaviors. For individuals who are unable to walk and/or use a manual wheelchair, powered mobility devices (PMD) provide and additional means of gaining independent mobility (3,4). Despite the increased availability of PMDs and improved, access to public accommodations and transportation, no studies have focused on the impact of powered mobility devices on daily life activities.

The transition from manual to powered mobility devices, is considered difficult, is resisted and accepted only reluctantly by persons who have previously used manual chairs (5,6,7). While PMDs increase independent mobility, they also represent the loss of a familiar means of mobility, and often represent diminishing capacity. Additionally, they require more complex adjustments in the human and non-human environments such as battery maintenance, ramps, power lifts, etc.

This study describes the impact of the transition from manual to power mobility on the quality of life and the assumption of responsibilities, the enactment of roles and pursuit of interests. It also examined the specific effect of PMD as an aspect of the non-human environment.

RESEARCH QUESTIONS

This study tested three hypotheses. The first is that using a PMD affects a person's occupational performance, i.e., their ability to assume or resume personally valued responsibilities, interests, and roles. The second is that the non-human environment supports or constrains the use of the PMD and subsequent occupational performance. The third is that the PIADS score which measures adaptibility, competence and self-esteem will be correlated with the impact of the PMD as measured by the post score from the OPHI.

METHOD

Eight participants between the ages of 27 and 52 who had received their first powered mobility device within 6 and 24 months were interviewed for the study. Diagnoses were cardio-pulmonary insuffiency, muscular dystrophy, multiple sclerosis, spinal cord injury, or traumatic brain injury. Particpants had the ability to compare life experiences with and without powermobility and were interviewed in their natural daily living environments where they had mobility independence.

Two instruments were used to quantify interview data: The Occupational Performance History Interview (OPHI) (8) and the Psychosocial Impact of Assistive Device Scale (PIADS) (9). The OPHI gave a pre and post score with the receipt of a PMD as a demarcation event. The OPHI quantifies interview data with 5 point scale in 5 domains: 1) organization of daily living routines; 2) life roles; 3) interests, values and goals; 4) perception of ability and assumption of responsibility; and 5) influences of the human and non-human environment. The PIADS measured the impact of the PMD on competence, adaptability and self-esteem. Participants rated themselves on whether personality characteristics increased or decreased with the PMD.

RESULTS

The mean OPHI pre score was 34.9 and the mean OPHI post score was 43.6. When analyzed with a dependent samples t-test, a statistically significant difference ($t=9.50$; $p=.0001$) in scores was found as the scores were highly correlated ($r=.934$), i.e., participants resumed or assumed personally valued responsibilities, interests, and roles. The change in mobility devices made a significant change in the OPHI non-human environment subscore. When analyzed with a dependent samples t-test, a statistically significant difference ($p=.0002$) in pre and post scores was found.

The correlation between scores on the PIADS and the post scores on the OPHI for each particpant could not be supported as the sample was too small to achieve a meaningful Spearman correlation ($\rho=.21$). However, the PIADS did indicate a significant impact by PMDs on the adaptability, competence and self-esteem of the persons who use them ($t=12.34$; $p=.0001$). The mean score for all participants was 47.25 which was compared to a mean score of 0, an indication of no psycho-social impact.

DISCUSSION

For the study participants, all of whom had severe disabilities, the meaning in their lives came from their roles. Most expressed a clear understanding of and devotion to their roles as father, advocate, mother, student, volunteer, entrepreneur, parental care taker, organizer, friend or counselor. The difference in pre-post OPHI scores were consistent with a significant change in participant's ability to pursue interests, take on responsibilities and enact roles after PMD use was introduced. Additionally, most had developed adaptive ways to undertake the various activities that enabled them to enact these roles. Within the time span (mean=13.6 months) most participants increased ability to enact previously valued roles and to engage in previously held interests.

A PMD supports or constrains performance depending on the accessibility of the environment. Functional limitations in mobility are significantly reduced through appropriate combined use of PMDs, accessible environments, attendant care and social supports.

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THE STABILITY OF IMPACT OF ASSISTIVE DEVICES [1]

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ABSTRACT

The impact of an assistive device can be felt in two ways; its effect on the functionability of the adopter, and its affect on his or her quality of life. The former has been researched intensively, but the latter can only now be measured with a new scale. Using this scale with eyeglasses adopters, we found that the psychosocial impact remains high over the first year of wear. This is important because it can help us predict abandonment of prostheses if the impact drops from positive to negative levels over time.

BACKGROUND

The impact of the adoption of an assistive device (AD) can be felt in a number of ways. Most commonly discussed is that an AD improves the function of its adopter. If the AD performs poorly, requires complex and expensive maintenance, or is difficult to manipulate, it may be abandoned. But a second important type of impact is on the quality of life of the adopter. There are psychosocial effects impacted by the presence, or absence of an AD. But there may be a conflict between the two. An AD may serve its functional purpose but may be embarrassing for the user, decrease self-esteem or feelings of control, and so may be abandoned.

There is a plethora of research on the adoption and retention of an AD linked to the functional aspects of the AD. Batavia, Dillard & Phillips (1990) for example, identified four major problems reported by consumers; inadequate performance by the AD, failure to achieve improved function by the adopter, difficulty in operating the device, and high maintenance costs. On the other hand there is a dearth of research on the impact of ADs on the quality of life (QOL) of the user. Phillips and Zhao (1993) reported that 29.3% of 1,732 devices prescribed to 227 adults had been abandoned often because they failed to meet their needs and lifestyle priorities. Other studies have alluded to the fact that abandonment of prostheses is often caused by their failure to satisfy the adopters. Abandonment results in a waste of money, effort and time. But the reason for the paucity of research on the impact of ADs on psychosocial aspects of life may be that there has never been a valid method of measurement . While some measures of functional impact include a few items on satisfaction, they tend to be general and inconclusive.

Recently, a measure was developed specifically to judge the impact of an AD on the (QOL) of the user. The *Psychosocial Impact of Assistive Devices Scale* (PIADS) was developed by Day and Jutai, and was reviewed in two RESNA workshops (Day & Jutai, 1995, 1998). It consists of a 26-item questionnaire which, when factor analyzed, yielded 3 distinct subscales which have been included in the literature as indices of quality of life. These are Competence, Adaptability, and Self-esteem. Day and Jutai (1996) demonstrated the utility of the measure in distinguishing the psychosocial impact of two commonly used ADs, eyeglasses and contact lenses. They found that on all three subscales, contact lenses had a more positive impact. The PIADS is the subject of a multi-center, international study to examine its validity and its clinical utility for a wide variety of ADs (cf. Gryfe & Jutai, 1998; Jutai & Gryfe, 1998).

RESEARCH QUESTION

However one aspect of an AD had not been examined as yet, namely, whether the impact on the (QOL) of the adopter remains effective over time. It might be argued that with continuous usage the AD becomes so much a part of the life of the user that it's impact would diminish. Examination of the literature on continuous exposure to an object found that this question has received little attention and that, where research had been conducted, it had yielded conflicting results. Slukin, Coleman & Hargreaves (1980) reviewed a large number of studies and postulated an inverted "U" curve linking liking to familiarity. But the expectation here would probably be that the adoption of an AD would be felt more positively at first but would wane in time as the user becomes more adapted to, or disaffected with, the device. It was therefor decided to study the impact of the adoption of eyeglasses over a period of one year.

METHOD

The subjects in this study consisted of all the patients admitted to the Centre for Sight Enhancement at the University of Waterloo for assessment of their eyesight and possible need for eyeglasses over a period of two months. Subjects were promised a total of $15.00 to participate in the study by agreeing to complete questionnaires three times over the course of a year.

Each participant received $5.00 at the first session for completing demographic information. After about one month all the participants were mailed the PIADS, together with a $5.00 bill. Participants who returned the tests in the second session were sent the PIADS about 11 months later.

RESULTS

The number of participants at the first session was 175; in the second session 129 returned the PIADS and 55 of those identified themselves as adopting eyeglasses. The adopters were sent another copy of the PIADS (with the $5.00) and 45 people returned the package.

t-tests were performed on the PIADS data of the 45 who returned the questionnaire on Times 2 & 3 and the 10 who didn't return it on Time 3, and no significant differences were found showing that, at least on adoption of the eyeglasses, the impact was similar.

A multivariate analysis was performed and the data clearly showed no change in impact over a year of wearing eyeglasses (see Figure 1). Scores on the Competence subscale were significantly higher than scores on the Adaptability and Self-esteem subscales, the same pattern as found in the study by Day & Jutai (1996). This reinforces the normative value of the data obtained from the original validation study of the PIADS.

DISCUSSION

The results show clearly that the impact of the adoption of an AD did not wane over one year. People adopting eyeglasses felt as positive a year after adoption as they did at adoption While this study was restricted to a one year period, earlier, as yet unpublished studies with the PIADS, have found that even over longer periods of time there was little diminution of impact.

The importance of these results lies in our need to explore long term impact of any AD on the life of its adopter. All too frequently we prescribe an AD and assume that the adopter will comply forever, continually using the prosthesis with no diminution of acceptability. This is the first study that has followed up the adoption of an AD over a one-year period and found that indeed, the impact remained high. Even if we assume that the 10 people in the study who failed to respond to the third session had stopped using eyeglasses, we still find that at the first month the impact was as positive as it was with those who continued to comply with eyeglasses wear.

The possibility of measuring the impact of an AD is important because we can then track it over time and predict possible abandonment of the AD if we find the positive impact waning. Also, so far, we have found that the impact of adoption of an AD is positive on all subscales of the PIADS, and highest in Competence, both for eyeglasses and contact lenses. We are now in the process of identifying the patterns for other prostheses

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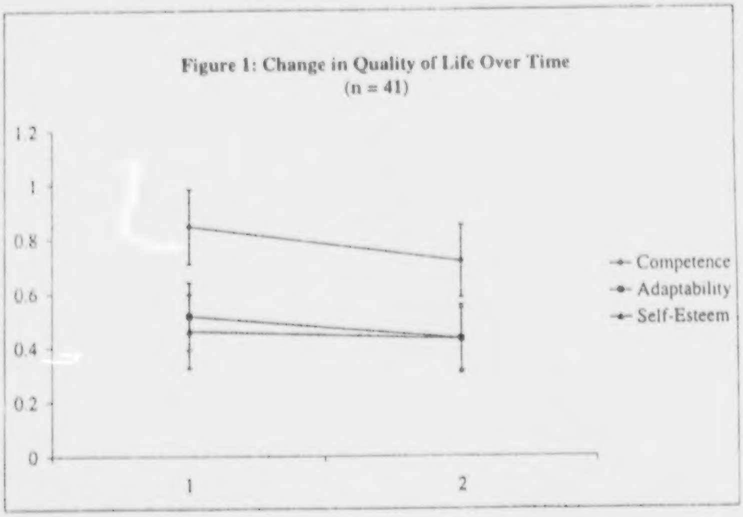
Figure 1: Change in Quality of Life Over Time (n = 41)

[1] Funding for this study was received from the Ontario Rehabilitation Technology Consortium.

ASSISTIVE TECHNOLOGY OUTCOMES IN THE SCHOOLS: IDENTIFYING A VALID MEASURE

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ABSTRACT

The recent reauthorization of IDEA mandates the consideration of assistive technology as a tool to enhance independent functioning in school activities. This simulates school administrators to better identify which assistive technology devices and services are most cost effective and provide the greatest impact. Currently, few appropriate assessment instruments are available to measure assistive technology in the schools. This study reviewed instruments and identified two that, with modifications, may be well suited for this task. The study examines the need for future research.

BACKGROUND

The reauthorization of IDEA in 1997 mandated that assistive technology be considered for all students with an IEP. This has demanded that educational facilities seriously consider the benefits of assistive technology. Administrators want to know that assistive technology is being applied in productive and meaningful ways.

The lack of appropriate instruments prevents the effective measurement of assistive technology outcome [1]. Few assistive technology instruments focus on assistive technology in the school setting. Still fewer of these are standardized. Informal methods of assessment do not provide a valid basis for empirically measuring the effectiveness of assistive technology over time. The lack of formal assessments in the schools prompted the development of the School Function Assessment [2].

RESNA has responded to this insufficiency through the development of the *RESNA Resource Guide for Assistive Technology Outcomes* [3]. The guide includes a volume on measurement tools [4] to assist practitioners in locating and choosing assessment instruments.

RESEARCH QUESTION

The literature reveals that although instruments exist to measure aspects of function and technology, none of these has been validated for use as an outcome instrument. The objective of this project was to investigate the potential assessment tools available and determine if any one of them or combination of the tools could be used as a valid measure of outcome in the schools.

METHOD

This study applied a comprehensive search for assistive technology assessment instruments. 27 instruments were found by literature review, expert interview and from the *RESNA Resource Guide for Assistive Technology Outcomes: Assessment Instruments, Tools, & Checklists from the Field* [4]. These 27 instruments were reduced to 9 using the following criteria: comprehensiveness, potential use for assistive technology in the schools, and versatility. These 9 tools were reviewed and pilot tested by 22 special education professionals on 1-3 students on their caseload.

Practitioners completed a questionnaire and a follow up meeting was held with the practitioners to discuss the instruments and gain feedback about how useful the instruments were as an outcomes tool. At the meeting, groups of practitioners who used the same assessment instrument discussed their opinions about the instrument, and completed a second questionnaire. The results from the questionnaires and subjective comments were aggregated.

RESULTS

The data from the follow up meeting identified a continuum of assistive technology service delivery models and where each of the 9 instruments resided on that continuum [5]. This data is presented in Figure 1.

Figure 1

	Screening	Referral	Comprehensive Assessment	Matching person and technolgy	Acquisition	Implemetation	Follow Up	Educationa l Impact
Lifespace Access Profile			■					
A.T. Screener			▨	■				
WATI	■	■	■	■	■	■	■	
Assessment for AT			■					
PEDI			▨					▨
SFA			■					■
QUEST								■
MPT				■				
SchoolFACT			■					■

Four instruments demonstrated components that might measure the educational impact of assistive technology (see column on the far right): School Function Assessment (SFA) [6], the Pediatric Evaluation of Disability Inventory (PEDI) [7], the Quebec User Evaluation of Satisfaction with assistive Technology (QUEST) [8], and SchoolFACT [9].

All four instruments however exhibited major drawbacks. QUEST measures the subjective components of outcome and focuses less on the educational impact. PEDI is not specific to school activities. The School Function Assessment and SchoolFACT were identified as instruments that best met all of the criteria, however neither explicitly measures assistive technology.

Further analysis among the research team revealed that these instruments might unmask their potential if there was a way to better focus on quantifying changes over time. Specific design modifications have been developed and protocols to test the reliability and validity of these versions have been created. Figure 2 highlights the SFA-AT compared to its original version.

Figure 2: Comparison of SFA and SFA-AT

SFA	SFA - AT
Penalizes participation score for assistive technology use.	Does not penalize participation score for assistive technology use.
Measures outcome using an environment adjusted method.	Measures outcome using the difference between environment adjusted and environment free methods.
Measures functional skill performance in school activities.	Measures impact of assistive technology.
Designed with medical model.	Designed on functional outcomes model.

SchoolFACT was designed specifically for measuring school function using Trichotomous Tailored Sub-branching Scoring (TTSS) as developed in OTFACT [10 1998 #184]. This system allows for efficiently scoring only domains of concern. SchoolFACT, however, must be revised to be more assistive technology specific. These revisions are in progress and are called OATSFACT.

DISCUSSION

While substantial attention in measurement has focused on outcomes in the schools and in assistive technology, few instruments combined these perspectives. This study devised two new aversions of existing tools to meet this combined need. Follow up research will identify if these modifications will produce the desired instrument. Further research is needed however to investigate the degree of reliability and validity.

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CALCULATION OF WORK AND POWER DURING WHEELCHAIR PROPULSION OF INDIVIDUALS WITH PARAPLEGIA.

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ABSTRACT

This paper investigated the work and power of individuals with paraplegia while they were propelling their own wheelchairs on a dynamometer at .89 m/s and 1.79 m/s (2 and 4 mph). Their wheelchair was fitted with SMART^{Wheel}s on both sides in order to collect kinetic data. This kinetic data was used to calculate the work and power for a twenty-second trial at both speeds. There were 17 subjects: 7 with less then 7 years and 10 with more than 14 years of wheelchair use. The work and power for the two groups were compared and none of the variables were significantly different. Future studies can investigate the work and power produced while an individual is propelling up to a maximal speed.

INTRODUCTION

Improved medical emergency services and technology has helped individuals survive what was once a fatal accident with some level of paralysis. This has lead to an increase in the number of manual wheelchair users each year (1). The smaller upper extremity musculature (compared to the large leg muscles) was not made to withstand the forces and trauma of producing mobility in a wheelchair for an individual with a spinal cord injury.

Wheelchair research has numerous studies investigating physiological power that includes aerobic and anaerobic power during manual wheelchair propulsion. Some of these studies also report the physiological work exerted by the individual while they propel a manual wheelchair (2 & 3). The mechanical work rate of the test trials has been reported but the overall work produced during the test trial has not been calculated (4). There is a limited number of research articles investigating the work and power produced during a manual wheelchair propulsion trial.

The purpose of this paper was to calculate the work and power produced by an individual propelling a manual wheelchair for a twenty second time trial at .89 and 1.79 meters per second (2 and 4 mph, respectively). Analysis included the variables: work, power and the work and power produced with each stroke during the twenty-second trials. It was hypothesized that there might be a difference between work and power of individuals who have been using a wheelchair for less then seven years and more than fourteen years.

METHODS

Seventeen subjects were selected from the Human Engineering Research Laboratories database in order to develop two groups using years of wheelchair use as the establishing criteria. The subjects answered a questionnaire about their wheelchair history and health prior to the testing. The subjects were divided by years of wheelchair use: one group had seven years or less of wheelchair use and the other group had more than fourteen years of wheelchair use. Table 1 represents the mean and standard deviation of the two group's age, years of wheelchair use and weight in pounds. ID# < 7 represents the individuals with less then seven years and ID# > 14 is the over fourteen years of wheelchair use groups. The ID# < 7 group's age ranged from 21 to 36 years of old, wheelchair use of 1.3 to 6.7 years, and weight of 106 to 184 pounds. While the ID# > 14 group's ranged from 35 to 53 years of old, wheelchair use of 14.7 to 25.2 years, and weight of 132 to 220 pounds.

The kinetic data were collected using SMART^{Wheel}s at a sampling rate of 240 Hz. The individual's wheelchair was fitted with SMART^{Wheel}s on both sides. The individuals original seat configuration was not changed. The wheelchair was then secured to a dynamometer. Data collection was synchronized (SMART^{Wheel}s) and collected via an IBM compatible computer. Raw kinetic data (A/D units) were converted to forces and where it was then analyzed using Matlab programs. The moment about the axle (Mz), measured by the SMART^{Wheel}s, and the angular displacement, measured by the optical encoder, were used to calculate work (Joules) and then work was calculated over the time period to compute power (Watts). The strokes were counted on the plot of work and used to calculate the work per stroke and power per stroke.

ID# <7	AGE	WC YRS	WT (lbs.)	ID# >14	AGE	WC YRS	WT (lbs.)
MEAN	25.67	3.74	149.89		41.60	19.21	173.10
SD	4.61	2.12	30.58		5.30	3.85	29.65

Table 1. Subject ID#, Age, Weight and Wheelchair Years of Use.

Testing consisted of the subjects propelling their wheelchair at .89 and 1.79 m/s (2 and 4 mph). The subject would propel up to the speed of that trial and then maintain the speed. Data for each trial were collected for twenty seconds after the subject reached steady state. The left and right work and power data were combined and averaged for a work average and power average for each individual before the group means and standard deviations were calculated. Statistical analysis of the work, power, work/stroke, power/stroke and subjects' weights was performed using a T-test in Excel with an $\alpha = 0.05$.

RESULTS

The results of work average (WRK), power average (PWR), work per stroke (W/ST) and power per stroke (P/ST) from this study are represented in Table 2 (Speed .89 m/s) and Table 3 (Speed 1.79 m/s). The tables show the groups: less then seven years (< 7) and more than fourteen years (> 14) of wheelchair use. There were no significant differences between the less then seven years or more than fourteen years of wheelchair use for any of the variables investigated, including the subjects' weights.

< 7	WRK (J)	PWR (W)	W/ST (J)	P/ST (W)
Mean	217.64	51828.57	13.54	3224.52
SD	113.11	26961.13	9.56	2278.56
> 14				
Mean	233.21	55520.00	12.70	3023.62
SD	80.95	19289.94	4.66	1111.16

Table 2. Trial Speed .89 m/s (2 mph)

< 7	WRK (J)	PWR (W)	W/ST (J)	P/ST (W)
Mean	345.85	85344.29	14.79	3520.59
SD	169.69	40403.49	9.46	2251.30
> 14				
Mean	355.02	84529.47	13.58	3233.12
SD	136.03	32387.21	6.29	1498.79

Table 3. Trial Speed 1.79 m/s (4 mph)

DISCUSSION

There were no significant difference found for the variables in this study: work, power, work per stroke, and power per stroke between two groups of individuals that use wheelchairs for mobility. One group had used the wheelchair for less then seven years while the other group had used the wheelchair for over fourteen years. The hypothesis was that a group that had used the wheelchair for twice as long as the other group might have a more efficient propulsion stroke. The means were similar between the two groups, but it should be noted that the standard deviations are smaller for the over fourteen years of wheelchair use for all the variables investigated for this study. This could indicate that over time the work and power an individual propels at for a steady state period become more homogeneous to individuals that have propelled a wheelchair many years.

The test trials were twenty seconds long and the individuals propelled at .89 m/s (2 mph) and 1.79 m/s (4 mph). Because the speed was the same for both groups and a steady state was maintained by each individual, it might be possible that an individual can become acclimatized to propelling a wheelchair rather quickly. An individual might adapt in the first year or so and be able to propel at a steady state as efficiently as someone who has been propelling for many years. It should be noted that the ID# > 14 group was older and this might affect their measured work and power production levels during wheelchair propulsion.

Future studies can investigate the work, power and the work and power per stroke during a start up trial, which involves the individual propelling up to a maximal speed as quick as possible. The efficiency when the individual starts to propel is an important factor when it comes to avoiding injury to the wrist and/or shoulder. The moment (Mz) that produces motion of the wheel is possibly higher during start up since the wheelchair is accelerating. This makes efficiency during start-up propulsion an important factor on limiting upper extremity loads and avoiding wrist and/or shoulder injuries.

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GAIT ANALYSIS USING A 3D GRAPHIC MODEL TO DRIVE IMAGE PROCESSING

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ABSTRACT

Gait analysis is a valuable tool in diagnosing walking disorders. However, the laboratories where such studies take place are often far from where the patients are. In this paper we describe a preliminary approach to using standard video for follow-up analysis. Techniques from graphics and human motion modeling have been combined to determine the patient's motion.

INTRODUCTION

Today, human leg motion has been widely studied and simulated. Some approaches have used several detectors, and multiple cameras to record the position of the leg and then used image processing to simulate the leg motion. In this work, our objective is to minimize the use of markers and cameras in order to provide a low-tech solution to gait digitization. In order to accomplish this, we are using a 3D model of the patient's leg to drive the image processing.

In our scenario, a patient has an initial visit to a clinic at which time information about the patient's leg geometry and pathology are recorded. After some treatment period has elapsed (e.g. wearing a brace or post-surgical recovery), a videotape of the patient walking is taken at a remote site and sent in for analysis. We are in the process of developing techniques to enable this analysis.

METHODOLOGY

Step 1: Leg modeling

For the initial stage of the project we created surface and skeleton data for a human leg. To obtain digital data for a human leg, we have downloaded 110 images from the "Visual Man" which were cross sections of the leg.(1) Each image was processed to extract the contour of the cross section. Each contour was digitized and connected to other contour data so that the surface of the leg was constructed. A digital model of the leg's bones was obtained from the internet.

Step 2: Image processing

The next step was to obtain gait data from a human subject without the use of markers. With the assistance of The Ohio-State University Gait Lab, video sequences of a subject's leg motion was taken. (In order to simplify the image processing at this time, the subject wore a red stocking on one leg and a black stocking on the other; this requirement will be eliminated as our image processing becomes more sophisticated). The video was recorded with different cameras at different positions; one camera was in the front of the subject and the other was at the side of the subject.

The side-view and front-view video was dumped to a digital disk. The silhouettes of the legs were extracted from the images; to reduce the noise, a cubic B-Spline curve was used to represent the leg contour. This curve was fitted to the contour data using the contour points as control points of the B-spline curve. This had the effect of smoothing out local variations in the contour data due to noise. Horizontal slices were taken through each scanline of the silhouettes and the midpoint of the slice was used to produce a central axis for each image. Thus, each axis consisted of one to two hundred points, one per scanline. Figure 1 shows a sample contour.

Step 3: 3-D leg motion simulation

The multiple 2D views of the leg motion, basic knowledge about the human anatomy, and velocity constraints on the motion were used to reconstruct the leg motion from the axis data. First, for each time slice, the two 2D axes were used to construct a 3D axis by constructing the planes of project from the camera setup, and then intersecting the projections of the 2D axes from the image planes. This resulted in, for each of the two legs, a single animation sequence of a 3D axis through time. These axes, however, still contained noise. In order to overcome the noise and to infer consistent upper and lower leg axes, the sequence was searched for the frames in which the largest curvature occurred at approximately the middle of the axis. This located the knee joint in each frame with some associated measure of reliability. By fitting straight lines to the upper and lower parts of this, a stylized leg could be constructed. The same process was used to locate the ankle in one or more frames. Once this was done for the set of frames, the more reliable points could be used as control points of a space-time curve to track the motion of the knee joint and ankle joint throughout the sequence. (This is somewhat inaccurate because the original 2D axis we constructed used the midpoint of the silhouette instead of something more anatomically appropriate; we will improve this in future work). The space-curve could also be used to infer the position of joints during frames in which data was missing due to occlusion. Once these joints were located in all frames, the entire skeleton could be constructed in all frames. The bone data was fit to this data as was the surface data created in Step 1.

RESULTS & DISCUSSION

Progress is being made rapidly in being able to do the tasks that we have set out for ourselves. Examples of the state of our work are given in the figures. Figure 1 shows a contour extracted from video. Figure 2 shows a frame of bone and contour animation.

Using video of a markerless human has proven to be a promising approach to analyze gait. We hope to improve on many facets of the approach in order to make the system more robust and to eliminate the many restrictions that our system currently has. However, we have successfully

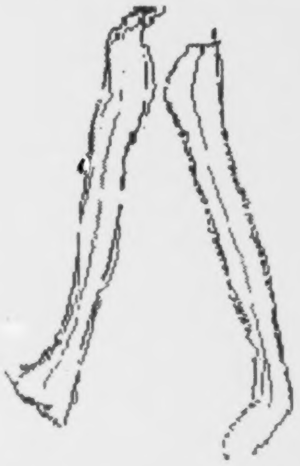

Figure 1 Extracted leg contour side view

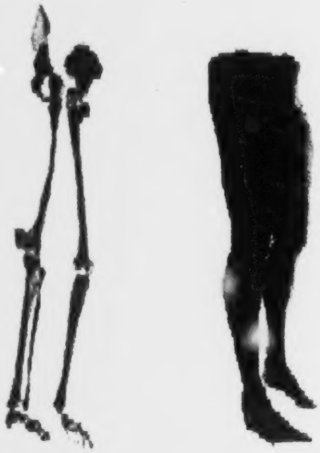

Figure 2 Single frame of motion and skeleton animation

analyzed video and recreated a human gait cycle with this technique. The next step is to simultaneously capture marker data and use it as a baseline comparison for our results. We have already used motion data from our gait lab to animate the initial skeleton and surface data.

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EXAMINATION OF THE MOMENTUM TRANSFER STAGE OF SIT-TO-STAND PERFORMED BY HEALTHY ELDERLY USING ACCELEROMETRIC & VIDEO DATA

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ABSTRACT

Momentum transfer is a critical sit-to-stand stage, which can determine the success or failure of its outcome. Nine healthy elders who performed sit-to-stand at normal speed were studied, using time markers extracted from video overlayed onto accelerometric data. Spearman rank correlations were run to examine sway and pitch relationships with percentage of time spent in this stage. A relationship was found between the percentage of time spent in momentum transfer with sway during the duration of the activity, and with flexion momentum and momentum transfer intervals.

BACKGROUND

The sit-to-stand (STS) activity is routinely performed on a daily basis by most individuals -- one must rise from a seated position before one can walk. The activity has been defined to consist of 4 distinct phases (Fig. 1) [1,2]: (a.) *Flexion momentum* (FM) begins with the first sign of upper body motion and ends just before the subject's buttocks come off the seat; (b.) *Momentum Transfer* (MT) begins the instant the subject leaves the seat and ends with maximum ankle dorsiflexion (In this stage, primarily forward momentum is transferred into upward momentum.); (c.) *Extension* (EXT) ends when the hips first become fully extended; (d.) A *settling* period then follows as motion returns to that of quiet standing. MT is the stage which has most influence on whether a STS failure will occur [1,2,3].

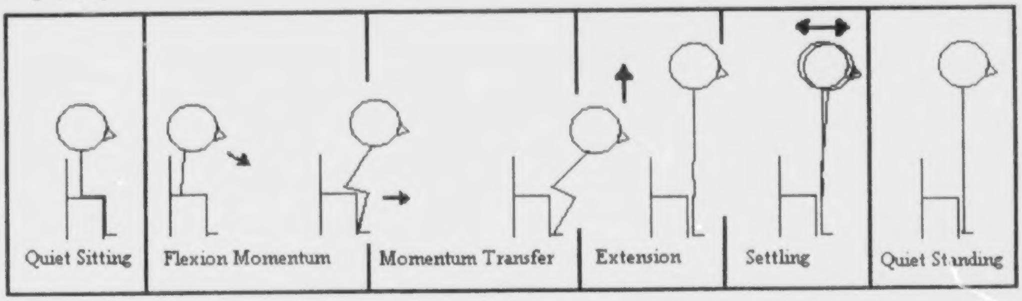

Figure 1. Stages of Sit-to-Stand

OBJECTIVE

Using data from a Wearable Accelerometric Motion Analysis System (WAMAS) and split-screen video data, we propose to determine whether a relationship exists between the percentage of time spent in the MT stage and physical stability during sit-to-stand performed by healthy elders.

METHOD

Eight healthy elderly subjects [3 female/5 male; mean age = 74.88 yr. (±4.29); mean height = 66.31 in. (±3.86); mean weight = 166.5 lbs. (±40.84)] were asked to perform sit-to-stand at normal speed with arms crossed at the chest. Each trial was repeated 3 times and videotaped from frontal and sagittal views. Upper body motion was recorded using the WAMAS, which consists of four 3-axes accelerometers (two at the head and two at the waist), and a wearable computer [4, 5]. Videotaped performances were partitioned, using frame counts, into the stages of sit-to-stand described above. The *settling* period was measurable in WAMAS data but not visible on video recordings, and was not included. The TOTAL time was defined to begin at the start of FM and end after EXT was complete. Start time was synchronized with the start of visible motion of the upper body for both video and accelerometric data. The duration of each stage was normalized by calculating the percentage of time spent in each stage as compared to the TOTAL.

Angular motion was estimated from the accelerometric data by using the following equations: AZX = 90deg - [ArcTan (**Z/X**)]*(180/Pi) = "pitch",
AZY = 90deg - [ArcTan (**Z/Y**)]*(180/Pi) = "sway", where, **Z** = acceleration in the vertical direction (g; $1g = 9.8 m/s^2$); **Y** = acceleration in the lateral direction (g); **X** = acceleration in the anterior-posterior direction (g). Keep in mind that each of the four sets of accelerometers consists of three accelerometers which are mounted orthogonally on a cube [4, 5]. With the body axis vertical, the Z-axis corresponds to the sensor which primarily records vertical accelerations, the Y-axis corresponds to lateral accelerations, and the X-axis corresponds to anterior-posterior accelerations. Measured accelerations are a composite of inertial (change in velocity) and gravitational components; the latter dominate when the body is tilted while the former are greater when the body is vertical.

Time intervals obtained from video frame counts were superimposed onto accelerometry data. Standard deviations (sd) of AZX and AZY were calculated for TOTAL and also each of the time intervals (FM, MT, EXT). Only accelerations measured at the waist were used for analysis since variations in head motions not related to the sit-to-stand activity (i.e., talking, head turning to look at equipment or operator) were present. Spearman Rank Correlation coefficients were calculated for the standard deviations, normalized intervals, and subject characteristics to determine the level of significance of their relationships.

RESULTS

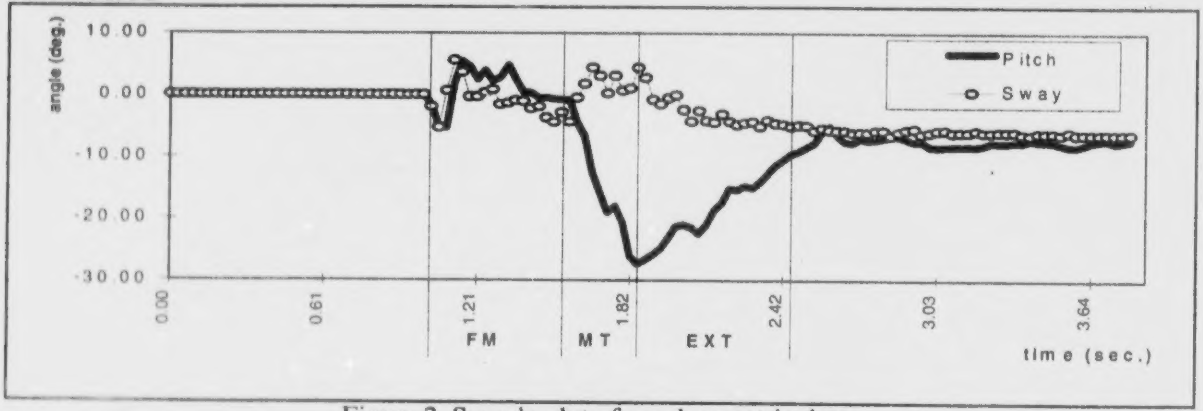

Figure 2. Sample plot of accelerometric data.

In Figure 2, a sample plot of accelerometric data collected at the waist sensors is shown with overlayed time markers extracted from video frame counts. The solid trace represents pitch angle and the dotted trace represents sway angle. At the beginning of FM, a slight lateral movement is observed as the sway and pitch angle briefly become negative. As the upper body flexes forward, pitch angle has a negative slope, accompanied by lateral motion. As the subject comes off the seat and approaches maximum ankle dorsiflexion in MT, sway fluctuates slightly and pitch angle abruptly becomes negative until a minimum is reached. As the hips approach full extension, pitch angle increases and sway diminishes.

Table 2 summarizes mean standard deviations and percent time intervals of data used in Spearman rank correlation calculations. Based on the Spearman Rank Correlation coefficients, the percentage of time spent in MT was found to positively correlate ($P<0.05$) with height ($r_s=0.81$), sway throughout STS ($r_s=0.93$), sway during FM ($r_s=0.83$), sway during MT ($r_s=0.79$), and percentage of time spent in FM (r_s=0.81). The percentage of time spent in EXT was negatively correlated (r_s=-0.95) with percentage of time spent in MT. Pitch did not show significant correlations with percentage of time spent in MT. However, pitch and sway during MT were significantly correlated (r_s=0.79).

Table 2. Data Table.

	TOTAL	FM	MT	EXT
sd AZX	19.29(sd=4.47)	3.01(0.90)	7.21(4.31)	8.19(2.00)
sd AZY	4.98(1.53)	2.38(0.98)	2.96(1.63)	3.17(0.85)
% time	-----	32.56(2.93)	18.16(5.08)	49.28(7.38)

DISCUSSION /CONCLUSIONS

MT is a critical stage in STS when the base of support is transformed from three points to two. It is the transitional state when primarily forward momentum becomes upward momentum. Essentially, MT is the stage which will determine the success or failure of the STS. An individual would fail the STS if they experience a sitback failure or fall forwards [1,2,3]. Sitback failures may be due to muscle weakness and impairment in balance control or coordination, resulting in a "lack of adequate momentum and torque generation" [3]. Likewise, lack of sufficient control when the center of gravity moves forward and outside of the base of support would result in a forward fall.

Results from this study suggest that the larger percentage of time spent in MT, the more likely that sway would increase during TOTAL, FM, and MT. One explanation might be that there is an increase in interruptions introduced during the transfer of momentum when more time is spent in this stage, resulting in a less smooth motion. This increase in sway does not affect the outcome of a successful STS. Another factor which may affect the smoothness of TOTAL, FM, and MT is the subjects' height. A taller subject would be required to move a further distance when coming off the seat during MT, resulting in a larger percentage of time spent in this stage. A larger subject would generate more momentum, possibly resulting in a greater amount of pitch and sway.

We conclude that there is a relationship between the percentage of time spent in MT with sway in TOTAL, FM, and MT during sit-to-stand performed by healthy elderly. Further study is required to determine whether this sway is related to instability in populations which tend to routinely experience STS failures.

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Seating and Mobility

IN SEARCH OF A BETTER UNDERSTANDING OF WHEELCHAIR SITTING COMFORT AND DISCOMFORT

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ABSTRACT

The purpose of this paper is to present the descriptors of sitting comfort and discomfort that constitute one of the components of the Wheelchair Sitting Comfort/Discomfort (CD) assessment tool under development. Two focus groups were conducted to identify factors associated with feelings of wheelchair sitting comfort and discomfort. The descriptors generated by the participants of this study confirm the multidimensional nature of comfort and discomfort and reveal how the wheelchair user perspective differs from that of non-disabled persons.

BACKGROUND

Comfort is one of the primary goals of wheeled mobility and seating aids. In a recent study on user satisfaction with wheelchair seating aids, results showed that comfort was considered to be the most important consumer criterion while at the same time it was the least satisfying (1). But what is sitting comfort ? In an ergonomic study with office workers, Zhang et al. (2) propose a conceptual model for perception of discomfort and comfort. In this model, discomfort is associated with biomechanical factors and fatigue while comfort is associated with feelings of relaxation; the two concepts are treated as different and complementary entities. Experts in ergonomic research on sitting comfort have developed both objective assessment techniques and subjective measures for evaluating chair comfort of office workers (3,4). Helander and Zhang (5) recently developed a Chair evaluation checklist that lists twelve descriptors of comfort and discomfort and two overall ratings of comfort and discomfort (Table 1).

Comfort descriptors	I feel relaxed I feel refreshed	The chair feels soft The chair is spacious	The chair look nice I like the chair	I feel comfortable
Discomfort descriptors	I have sore muscles I have heavy legs	I feel stiff I feel uneven pressure from the seat/back	I feel tired	I feel restless I feel uncomfortable

Table 1. Comfort and discomfort descriptors for non-disabled office workers (5)

To date, there have not been any studies that have examined how these descriptors might be similar to or different from the factors associated with wheelchair sitting comfort and discomfort.

RESEARCH QUESTIONS

What factors are associated with wheelchair sitting comfort and discomfort? Are the factors associated with sitting comfort and discomfort for wheelchair users similar to those for non-disabled office workers?

Objectives : This study was conducted as the first step in the development of a new outcomes measurement tool, the Wheelchair Sitting Comfort /Discomfort (CD) assessment tool. Two focus groups were conducted to define the multidimensional nature of wheelchair sitting comfort and discomfort and a pilot test of the CD tool was conducted. The main objectives of the focus groups were to identify those factors that are considered to be associated with wheelchair sitting comfort and discomfort, to improve upon the clarity of the comfort and discomfort descriptors that emerged from those groups and to discuss the content and format of two versions of the CD assessment tool.

METHOD

Sample: The first focus group was composed of nine participants; six experienced wheelchair users with a range of disabilities and three occupational therapists specialised in the area of wheelchair seating. Although the same individuals were asked to participate in the second focus group, two of the wheelchair users could not participate a second time and as result one new wheelchair participant was recruited.

Focus group 1 : The participants were first asked to think about those factors that could be associated with their feelings of wheelchair sitting comfort and discomfort; they were invited to write their feelings in terms of descriptors of comfort and discomfort. According to a modified version of the Nominal Group Technique (6) the participants took turns in verbally expressing the factors they considered to be associated firstly with wheelchair sitting comfort and then with sitting discomfort. The moderator recorded the descriptors on a flip chart for all to read and discuss. Then, from a list of comfort and discomfort descriptors that had been identified in the ergonomic literature, the participants were asked to select any of these items that they felt should be added to their own responses. A final list of 26 descriptors of sitting comfort and 22 descriptors of sitting discomfort emerged. Lastly, they were asked to individually select the 10 descriptors they considered to be the most important in each category and to rank them in order of importance. The focus group ended with comments and suggestions for improving the content and format of the first version of the CD assessment tool.

Focus group 2 : The second focus group was conducted one month after the first. Prior to attending the second focus group, the participants received in the mail, the ranking results of the descriptors generated in the first focus group as well as a second version of the CD assessment tool. The remaining non-selected descriptors were presented and the participants were asked to select from these excluded descriptors, the five most important descriptors of comfort and of discomfort and then to rank them in order of importance. Lastly, as part of the content validation process, the participants took turns in commenting on the second version of the CD assessment tool.

RESULTS

A total of 31 descriptors emerged from this study (Table 2).

Comfort descriptors	
1. I feel good	9. I have a good endurance level in my wheelchair
2. I feel supported in the right spots	10. I can move effortlessly
3. I feel little pressure under my buttocks	11. I can easily adjust the wheelchair components
4. My wheelchair and I are one	12. I feel satisfied
5. I can perform my activities	13. I can manoeuvre my wheelchair when I adopt the right position
6. I feel stable	14. I feel relaxed
7. The dimensions of my wheelchair are adequate	**15. I feel comfortable**
8. I can easily change positions in my wheelchair	
Discomfort descriptors	
16. I have pain	24. I feel physically tired
17. I need to move	25. I have to make an extra effort in order to maintain my position
18. The wheelchair's surface is too hard	26. I need to radically change position
19. The wheelchair limits my activities	27. I feel a burning sensation
20. I feel unstable	28. I lose my balance
21. I need a better seat or backrest support	29. I feel stiff
22. I am preoccupied by my seated position	30. I slide in my wheelchair
23. The wheelchair hinders my movements	**31. I feel uncomfortable**

Table 2. Wheelchair sitting comfort and discomfort descriptors

There were 14 descriptors of comfort, 15 descriptors of discomfort and two overall ratings of comfort and discomfort.

DISCUSSION

The descriptors generated by the participants of this study confirm the multidimensional nature of sitting comfort and discomfort and constitute the first step in the development of the Wheelchair Sitting Comfort/Discomfort (CD) outcomes measurement tool. These descriptors will be used with a 5-point scale whereby the wheelchair user will rate the degree to which they are true or false. Close scrutiny of Tables 1 and 2 reveal that both non-disabled workers and wheelchair users associated feelings of well being with sitting comfort. Unlike the office worker group however, the participants of this study did not identify the aesthetics of the chair as being an important factor of wheelchair sitting comfort; they described their feelings of comfort rather in terms of their ability to perform specific functional activities. For both groups, the discomfort descriptors were closely related to biomechanical factors and fatigue. Unlike the office worker group though, the participants identified particular wheelchair components and physical constraints as being related to sitting discomfort. In conclusion, from both a clinical and a research perspective, the results confirm the need to acquire a better understanding of wheelchair sitting comfort and discomfort and to test the (CD) outcomes measurement tool with a wheelchair user population.

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ELDERLY NURSING HOME RESIDENTS' SATISFACTION WITH MANUAL AND POWERED WHEELCHAIRS

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ABSTRACT

This paper presents the preliminary results of a study on the satisfaction of elderly nursing home residents who use a manual or powered wheelchair. The Quebec User Evaluation of Satisfaction with assistive Technology (QUEST) was administrated to 32 subjects. The variables scored as being the most satisfying were *simplicity of use*, *effectiveness*, *professional services* and *safety* with the wheelchair. Subjects were the most dissatisfied with wheelchair *adjustments*, *comfort*, *weight* and *follow-up services*. Differences in the satisfaction level between manual and powered wheelchair users were found for three variables. The results provide a better understanding of the sources of wheelchair satisfaction and dissatisfaction from the elderly person's viewpoint.

BACKGROUND

Over 80% of elderly persons have difficulty walking or are unable to walk (1). In a nursing home setting, many residents, although they are physically capable of walking, choose to use a wheelchair because of pain, fear of falling and decreased strength, endurance, vision and balance (2). Generally, wheelchairs are prescribed to optimise functional abilities and to provide a proper and comfortable seated posture (3). In a survey on the seating problems of 139 elderly wheelchair users, Shaw and Taylor (4) found that 80% of them had experienced at least one wheelchair problem and 34% considered this problem to be severe. They reported problems of discomfort, reduced mobility, poor posture and safety risk. Mann and colleagues (1) revealed that the elderly experience a high rate of problems related to maintenance, repair, fit of the wheelchair to the user and specific characteristics of the wheelchair. The majority of elders living in institutions remain seated in uncomfortable standard sling-seat folding chairs designed for short-range transportation and sized for tall people (5). The overall purpose of the study was to examine the relationship between functional independence of elderly nursing home residents and satisfaction with their wheelchair. The specific objective of this paper is to present some of the preliminary satisfaction results and to disclose the differences in satisfaction found between the users of manual and powered wheelchairs.

RESEARCH QUESTION

How satisfied are elderly nursing home residents with their wheelchair?

METHOD

Sample

Thirty-two elderly persons (65 years of age and up) were recruited from three long-term care facilities located in the Montreal area. The sample consisted of 23 women (72 %) and 9 men (28 %) with a mean age of 78 years. The subjects were using a manual (n=21) or a powered wheelchair (n=11) on a daily basis for at least three months.

Procedure

The Quebec User Evaluation of Satisfaction with assistive Technology (QUEST) was used to evaluate the subjects' satisfaction with their wheelchair (6). At the time of this study, QUEST consisted of 20 satisfaction variables that represent those criteria considered to most likely influence user satisfaction. The subject was asked to rate the degree of satisfaction for each of these variables using a 5-point scale, with 1 being «not satisfied at all» and 5 being «very satisfied». For variables scored 3 or less, the evaluator inquired into the sources of dissatisfaction. An overall global satisfaction score was also obtained.

RESULTS

The overall satisfaction scores showed that 56% (n=18) of the subjects were very satisfied with their wheelchair, 25% (n=8) were quite satisfied, 16% (n=5) were more or less satisfied and 3% (n=1) were not at all satisfied. Four variables were eliminated from the statistical analysis because they were scored non-applicable by an important number of subjects: *cost*, *service delivery*, *transportation* and *device compatibility*. Out of a total of 16 variables, the four most and the least satisfying are shown in Table 1. The most satisfying variables were *simplicity of use*, *professional services*, *safety* and *effectiveness* with the wheelchair. The least satisfying variables were the wheelchair *adjustments*, *comfort*, *follow-up services* and *weight*.

Table 1. Criteria considered the most and least satisfying for elderly wheelchair users (n=24)

MOST SATISFYING	Mean & SD	LEAST SATISFYING	Mean & SD
Simplicity of use	4.69 ± 0.59	Adjustments	3.78 ± 1.31
Professional services	4.59 ± 0.87	Comfort	3.94 ± 1.27
Safety	4.56 ± 0.88	Follow-up services	4.10 ± 1.32
Effectiveness	4.50 ± 1.02	Weight	4.18 ± 0.98

Significant differences (p. <0.05) were found when the Mann-Whitney-U test was performed to compare manual and powered wheelchair users (Table 2). The powered wheelchair subjects (n=11) tended to be less satisfied with the *durability*, the *multi-purposefulness* and *safety* with their wheelchair than did the subjects with manual wheelchairs.

Table 2. Satisfaction level differences between manual and powered wheelchair user

	MANUAL WC (N=21)		POWERED WC (N=11)			
VARIABLES	Mean rank	n	Mean rank	n	Z value [a]	2-Tailed P [b]
Durability	17.83	20	10.85	10	-2.2997	.0215
Multi-purposefulness	18.00	19	10.77	11	-2.5186	.0118
Safety	18.74	21	12.23	11	-2.3636	.0181

[a] corrected for ties [b] p<o.o5

DISCUSSION

The preliminary results of this study showed that more than 80% of the subjects were overall satisfied with their wheelchair. The principal sources of satisfaction were the *simplicity of use*, the *effectiveness* and *safety* with their wheelchair as well as the *professional services* they received. Almost all subjects thought their wheelchair was easy to use and were meeting their expectations. When a wheelchair problem occurred, subjects reported that they appreciate the fact that they were able to get the required services without going far and having to wait for an appointment. This serviceable context probably had a positive influence on their perception of the wheelchair safety. On the other hand, the principal sources of dissatisfaction were the wheelchair *adjustments*, the person's *comfort*, the *weight* of the wheelchair and the *follow-up services*. When asked to explain their dissatisfaction, the subjects found that the footrests and armrests were often too low, too high, too short or too long. They also complained that these components moved very easily after they had been fixed. When asked about their comfort, many of the subjects complained mostly about back pain in addition to leg, neck and buttock pain.

When the sample was divided into two groups according to type of wheelchair, the results revealed significant statistical differences in satisfaction between manual and powered wheelchair users for three variables: *durability*, *multi-purposefulness* and *safety*. Subjects with a powered wheelchair tended to experience frequent breakdown of their equipment. These durability problems also had an impact on their perception of wheelchair safety. The subjects explained that they were scared to use their powered wheelchair when they had to go outside the nursing home and cross a street because they had already experienced battery failure and problems with their control box. Dissatisfaction with the multi-purposefulness of the wheelchair was explained in terms of accessibility problems. Subjects with a powered wheelchair reported having difficulty accomplishing their activities of daily living because the wheelchair was too wide or too high to allow access under the sink and consequently several of them were forced to also use a manual wheelchair. Finally, subjects with a manual wheelchair seemed to be more satisfied with the multi-purposefulness of their wheelchair because they were able to use it for multiple purposes and different activities. In conclusion, the preliminary results of the study confirm the importance of obtaining consumer satisfaction outcome data and provide a better understanding of the sources of wheelchair satisfaction and dissatisfaction from the elderly person's viewpoint.

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CARER REMOTE CONTROL FOR A CHILDREN'S MOBILITY AID

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ABSTRACT

As part of a continual process to improve it's products and as a result of feedback from parents and carers, the Institute is developing a radio frequency remote control for it's powered mobility aid for children. This paper describes the components used and the method adopted to achieve reliable remote control for the carer whilst minimising any obvious physical intervention when the child steers into a dangerous environment.

BACKGROUND

The Institute has developed electrically powered mobility aids, the Infant and Junior Buggies (*Figure 1*), for children between the ages of 18 months and about 7 years who have cerebral palsy(1)(2). The devices have been very successful, particularly in encouraging the development of pre-school children. Whilst a child is learning to use one of the devices it is often necessary for the carer to intervene to get the child out of a difficult situation. This entails following the Buggy around and taking over the child's joystick when the child becomes stuck against an obstacle. The therapist or carer also has to take over control if a potentially dangerous situation arises when a more experienced child is using the Buggy in a risky situation such as driving on the pavement.

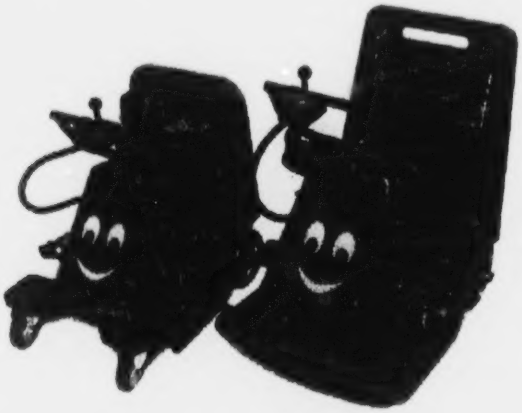

Figure 1 Infant & Junior Buggies

STATEMENT OF THE PROBLEM

A hand held remote control device, similar to a television remote control, is needed to enable control of a Buggy from a distance. The device would enable a carer or parent to supervise a child's learning process and to extricate them from difficult situations without having to physically intervene with the child's joystick. The device would also enable the carer to closely supervise a child using a Buggy in a more risky situation such as on a pavement, and enable the carer to override any dangerous manoeuvres or stop the device immediately if a dangerous situation arose.

If the remote control is to be effective its use must be very intuitive, i.e. it's method of operation must be obvious. It must be easy to change into the "override mode" from normal use and vice versa, and must not be susceptible to, or cause interference. In particular when the device is being used to supervise risky situations any intervention must be immediate.

RATIONALE

It is possible to fit both sizes of Buggy with a hard-wired carer-operated remote control. Although carers have found this addition to be invaluable, the fixed length of a cable connection requires them to follow the Buggy very closely at all times. A 'wireless' version of this remote control which retains all the necessary functionality, would be considerably easier to use as well as further reducing the child's perception of being supervised.

DESIGN

Concept Evaluation

A hard-wired carer-operated remote control was initially installed in a Junior Buggy which is regularly used to assess a child's suitability for various control options such as joystick, hand-switch or head-switch. This consists of a handheld box containing a switched joystick and an illuminated latching button (*Figure 2*). The joystick is constrained to move in four orthogonal directions and is mechanically biased to return to a neutral centre position. While the joystick of the remote control is in a neutral position the child's joystick operates normally and controls the direction of motion of the Buggy. Any operation of the carer's joystick immediately overrides the child's control of the Buggy. In addition, the carer can disable the child's joystick completely by operating the latching button, which illuminates to indicate this option has been selected. The carer-operated remote control is connected to the rear panel of the Buggy by a detachable plug. Operating a switch on the rear panel of the Buggy can also disable the remote control.

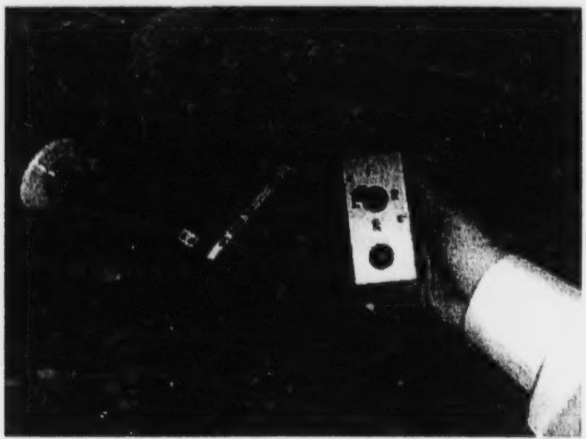

Figure 2 Hard-wired carer remote control

Feedback from carers and parents who tried the system indicated that this accessory was extremely useful, especially when the child was initially coming to terms with their new-found mobility. The main drawback to the system for the carer is having to follow relatively close behind the Buggy while it is moving. Occasionally the connecting lead can be over-extended resulting in wire failure despite using a flexible coiled lead.

Prototype Design

The design of an improved carer-operated remote control required a 'wireless' link to the drive electronics of the Buggy. Two methods were considered, infrared and radio frequency (RF) telemetry. An infrared method was discounted because of it's inherent directionality and greatly reduced range when used outside in bright, sunlit conditions. The RF option was preferred due to the wide availability of cost effective, pre-built and aligned RF modules, which are relatively simple to interface to digital systems. The modules chosen were FM telemetry modules operating at 418MHz, which is a licence exempt frequency in the U.K. for telemetry and tele-command. The transmitter module would be incorporated into a comfortable handheld controller for the carer while the receiver would be incorporated as an add-on module to the standard Buggy drive electronics.

The Institute's most recent Buggies contain custom drive electronics incorporating a microcontroller. This opened the possibility of serial communication between the telemetry receiver module and the drive electronics for remote control. It was decided, however, to design the receiver unit so that it could be inserted in the control lines of the Buggies' existing joystick and act as a 'steering filter'. This would allow it to be retrofitted to older Buggies, which do not incorporate a microcontroller.

The transmitter and receiver units both use Microchip PIC16C84 microcontrollers and Holtek HT12-D and HT12-E pulse position modulation encoder ICs. These devices ensure reliable communication between the transmitter and receiver units even in the presence of spurious external transmissions at the receiver frequency.

To enable the child's joystick and allow the child to take control, the carer must hold down a trigger on the remote control unit. This causes the remote control to transmit bursts of data every 500ms. The receiver interprets this data as a 'keep alive' signal and permits user control. If, for example, the carer was distracted and the Buggy were to drive beyond the relatively short range of the transmitter unit, the receiver unit would 'time out' and the child's joystick would be disabled, thus immediately halting the Buggy. If the carer deliberately releases the trigger, the remote control will transmit a continuous ten-second data stream which will also stop the Buggy immediately. At any time, operation of a small joystick on the top of the remote control will also allow the carer to override the child's joystick and steer the child away from any hazardous situation.

DEVELOPMENT

A prototype has been built and tested to assess the reliability of RF remote control. The transmitter and receiver units constructed only permitted remote steering and didn't provide the facility to override the child's joystick. These tests proved the feasibility of the system and showed that acceptable range and reliability were possible even in the presence of any interference from the switching PWM motor drive of the Buggy. The full system, including building the transmitter unit into an ergonomic, handheld unit is currently under way.

EVALUATION

Evaluation of this system is very much a continuous part of the overall design process. A remotely controlled Buggy was tested by paediatric therapists to ensure that the control concept was intuitive. The whole system will undergo extensive trials before being placed on the market.

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The enhancement of mobility for individuals who are both physically and visually disabled

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Abstract:

This study assessed the effectiveness of an electronic travel aid, the Nurion Wheelchair Pathfinder to determine whether it improves wheelchair mobility by: 1) decreasing the number of obstacles a person may bump into, 2) decreasing the amount of time to maneuver, 3) warning the person of oncoming drop-offs, such as curbs, and 4) assisting the person with directional orientation. The Nurion Wheelchair Pathfinder uses ultrasonic and laser technology to predict oncoming obstacles or drop-offs in the environment for individuals with both physical and visual disabilities. This study indicates that the device improved the mobility of persons with visual impairments who use wheelchairs within a familiar environment.

Background:

As new technology develops, occupational and physical therapists, are evaluating and prescribing more sophisticated devices to assist individuals with both physical and visual disabilities. Electronic travel aids, (ETA's) are ultrasonic or laser devices which were originally developed to assist individuals with visual disabilities for orientation and mobility (1). Nurion Industries developed an ETA that has both laser and ultrasonic technological capabilities, known as the "Nurion Wheelchair Pathfinder (NWP)(2). The NWP mounts onto a wheelchair and uses either beeps or vibrations to warn the individual of obstacles or drop-offs in their path. Cook & Hussey (1), state that certain consumers who are physically and visually impaired would be totally dependent for mobility without the use of this system. According to the Elwyn Experience (3), two women gained greater independent and safety around the campus with this new technology. There are two studies to date which assess the effectiveness of the previously developed ETA, the "Step Forward Sensing Device", Kuyk (4), and Farmer (5). This researcher was unable to find follow-up discussion or research related to their findings which addressed a few problems with the unit. According to Smith (6) who has recently worked with individuals using the unit, the NWP has improved individuals' mobility, but with restrictions depending upon the environment.

This study examined the effectiveness of the NWP to improve the orientation, safety, and mobility of a number of individuals with both physical and visual disabilities. It is the researchers intent that this information could assist professionals in the appropriate selection of mobility aids. In addition the study could support the justification of payment by third party payers and could prevent underuse and abandonment of assistive technology equipment.

Materials and Methods

Participants were four individual's who were both physically and visually disabled. They included three individuals who used a manual or power wheelchair and who had significant visual impairments, causing them to bump into many objects throughout their environment, and one individual who was blind.

Each participant was trained individually, and took varying amounts of time to be successful. A mobility instructor from the Commission from the Blind assisted in the training of the first participant who was totally blind. The NWP has different pitched beeps for sensing objects to the right and left sides, an intermittent beep at another pitch for the forward sensor, and a low pitched beep for drop-off sensor. The training took approximately 2 months, one to two times per week depending upon the availability of each participant. Data was collected on the number of correct times they verbally labeled the beep to the corresponding sensor. The participants needed to recognize and distinguish between the four different beeps 90% of the time before the actual testing began.

A single subject A B A B design was used to collect data on four individuals maneuvering through varying obstacle courses with and without using the Wheelchair Pathfinder. Numerical data was collected and graphed on the following variables: 1) number of bumps into objects, 2) amount of time it took to go through the obstacle course, 3) number of times the participant needed to be reoriented, and 4) number of responses to the drop-off sensors.

Results:

The resulting data indicated that the number of times the participants bumped into obstacles was reduced significantly with the Nurion Wheelchair Pathfinder. Table 1 summarizes the mean difference and the significance between using and not using the NWP for all the participants at the 0.05% level. It took all the participants longer to navigate with the device to go around obstacles rather then bump into them, but only by an average of one minute and less with participant 4.The drop-off sensor was consistent for a steep angle drop-off, but not for a gradual sloping drop-off. There were no significant differences in reorientation.

Discussion:

This study indicated that the Nurion Wheelchair Pathfinder improved the mobility of the participants who are visually and physically disabled within a familiar environment, but was inconsistent for drop-off use. Further research is needed to evaluate this device in various environments.

Other observations were that the NWP seemed to assist individuals' with cerebral palsy from the visual and motor neglect experienced on one side. Further studies are needed to assess the therapeutic value of the device for wheelchair users who have visual and physical difficulties caused by unilateral neglect, or hemiperesis. The NWP may also assist therapist in wheelchair mobility training for individuals with visual disabilities by giving extra auditory feedback to cue individuals to scan their environment better.

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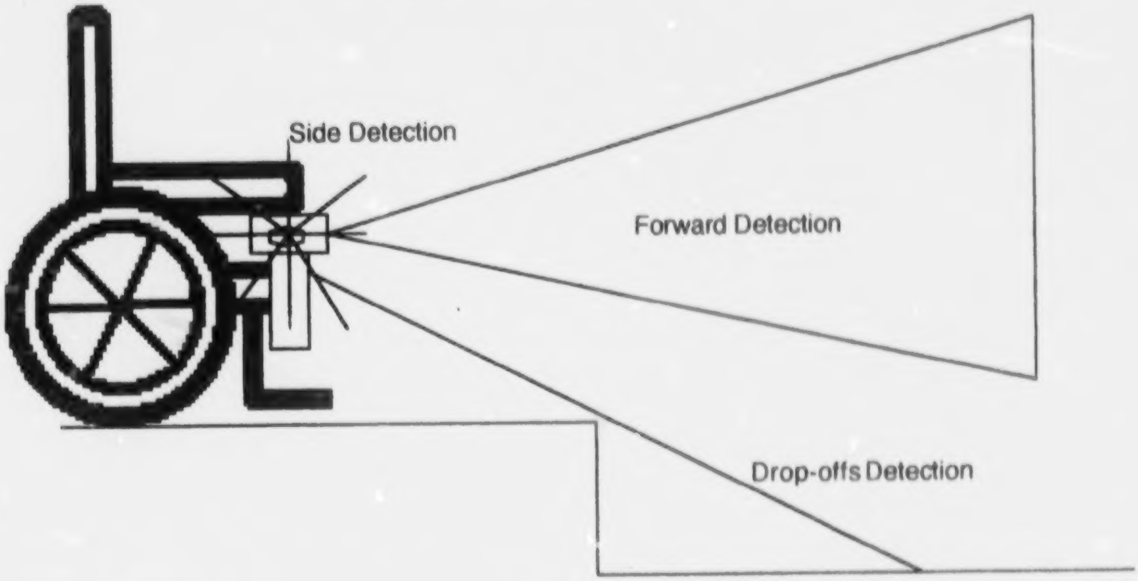
Figure 1 **Nurion Wheelchair Pathfinder**



Mean scores and significance

Table 1

Number of Obstacle Course Hits : 2-tailed t-score to significance of 0.05

	Mean with NWP	Mean without NWP	Mean difference	2-tail Significance
Participant 1	25.1	40.5	15.4	.000
Participant 2	4.9	9.9	5	.003
Participant 3	3.4	7.7	4.3	.002
Participant 4	.5	1.5	1	.111

COMPARISON OF BODY-SEAT INTERFACE PRESSURES WITH DIFFERENT WHEELCHAIR BACKS AND SEATS

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ABSTRACT

Clinical work in wheelchair seating has lead to the observation that it was possible to affect dramatic changes in seat pressure distribution solely based upon selection of seat back. Three seat backs and two seat cushions were used in this study to systematically investigate their effect on body-seat interface pressure. The system tilt angle was varied while holding seat to body angle constant at approximately 102° and the seat to body angle was varied while holding system tilt angle constant at approximately 5°. The results showed that significant differences could be obtained between the various combinations tested. However, the ranking of the combinations was not consistent between subjects.

BACKGROUND

It is widely believed that wheelchairs and seating systems impact upon the risk of secondary conditions such as pressure-sore development (1-2). Normal forces at the body-seat interface are strongly believed to be the primary causative factor in pressure-sore development. Studies demonstrate that changes in posture affect pressure at the body-seat interface (2-4). In these studies, different methods were used to change posture including changes in the system tilt angle, the seat to back angle, forward flexion of the truck away from the seat back, lateral bend of the trunk, and change in foot-rest height. Shields and Cook (5) changed posture with a lumbar support and saw significant decrease in pressure at the body-seat interface. In general, review of the literature reveals a paucity of information on the impact of seating-system backs on interface pressures.

At the same time, different seat cushions/surfaces have been used in these studies of posture and normal forces at the body-seat interface. Jay, Roho, polyurethane foam, flat foam and contoured foam cushions as well as hard surfaces without a cushion have been compared and contrasted in various combinations. Koo et al. (4) found that sitting postures do significantly affect ischial pressure, but that the Roho cushion was significantly more efficient in compensating the adverse effects of sitting posture on interface pressure as compared to a polyurethane foam cushion. Gilsdorf et al. (6) found that elevation of the foot rests increased the ischial tuberosity pressure with a hard surface and the Jay cushion while there was only a small pressure change with the Roho. These studies demonstrate that cushion selection can temper expected effects of posture changes on body-seat interface pressures.

RESEARCH QUESTIONS

The hypotheses of this study are: (a) the body-seat interface pressures will change as system tilt angle and seat to body angles change; (b) given the same seat cushion, the body-seat interface pressures will be different with different wheelchair backs; (c) given the same wheelchair back, the body-seat interface pressures will be different with different cushions.

METHOD

Four able bodied subjects, two female and two male, participated in the study. Each was dressed in cotton hospital scrubs. Each subject met inclusion criteria of specified measurements of seat width, seat depth, and lumbar spine flexibility.

A combination of three seat back cushions and two seat bottom cushions was used. Subjects were sequenced through a range of angular positions for both system tilt angle (STA) and seat to body (STB) angle in five degree increments (5 to 45° tilt (STA), and 100 to 160° recline (STB)). The seat back cushions were: 2.54 cm foam, Jay Contour, and Roho Adjust-A-Back. The seat bottom cushions were Jay 2 and high profile single valve Roho. The inflation of the Roho seat cushion was adjusted for each subject using the pressure measurement instrument. The Roho cushion was inflated for optimal pressure distribution as gauged by the simultaneous pressure mapping with the chair and back in the extreme upright position (5° tilt and 100° recline).

The subjects were positioned in the wheelchair so that the arm rests and headrest placed the shoulders and head in neutral positions. The foot rests were positioned to maximize pressure distribution over the thighs and buttocks with the chair and back in the upright position. The seat backs were positioned with the lower edge of the seat back at 2 centimeters below the posterior superior iliac spines.

RESULTS

Normal pressure measurements were made using a Xsensor pad and data acquisition unit. For each wheelchair position (or matrix of pressure pad readings), three summary values were collected: (1) total pressure in kPa, (2) the maximum pressure reading of any cell on the pad, and (3) the mean pressure, or average pressure of all non-zero reading pressure cells. These readings were normalized by dividing them by the subject's body weight.

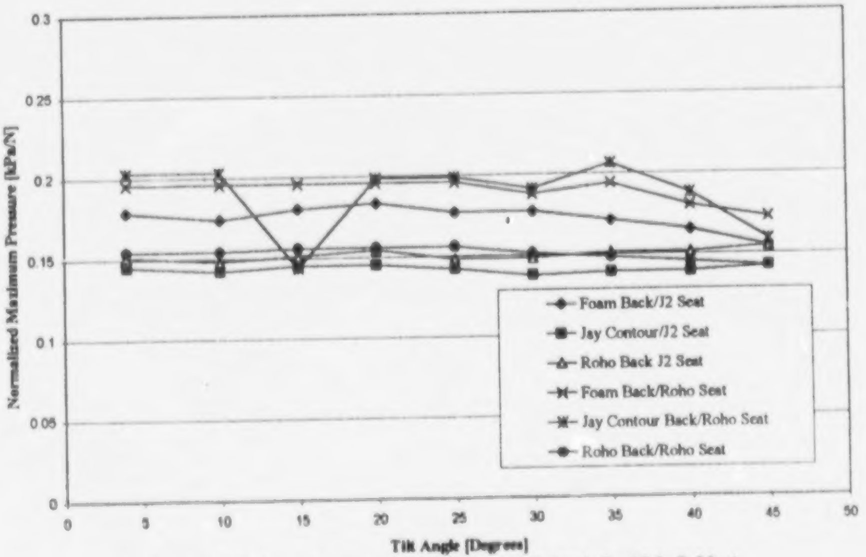

Figure 1. Maximum Pressure Dependence on Tilt Angle for Male Subject

Surprisingly, the normal pressure was independent of tilt angle as shown in Figure 1. However, normal pressure was a function of recline angle as shown in Figure 2. While the relative ranking of a seat cushion/seat back combination are generally consistent for a given subject, the ranking of a given combination does not hold between subjects. Another observation that can be made, not shown in the figures, is that variations between cushion/ seat combinations of 25 to 50% in mean pressure, become variations of

50 to 100% in peak pressure.

DISCUSSION

For some subjects there were cushion-back combinations that consistently produced lower interface pressures. Yet, inconsistent rankings of pressure measurements of cushion/back combinations between subjects suggests that no one cushion/back combinations was the best for decreasing interface pressures. The overall decrease of normal pressure with increasing body to seat angle is expected and when scaled by body weight agrees quantitatively with Gilsdorf et al. (5). The lack of dependence of normal pressure on system tilt angle was unexpected. This result was consistent among all subjects and thus does not seem to be anomalous.

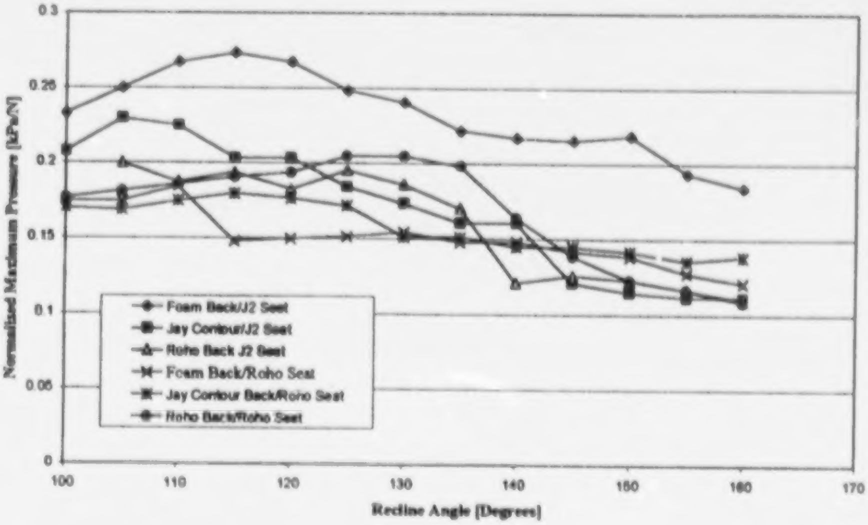

Figure 2. Maximum Pressure Dependence on Recline Angle for Female Subject

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MEDIUM DURATION SEATING FOR THE AMBULATORY ELDERLY: 'CAUSE SITTIN' AROUND SHOULDN'T BE A PAIN

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ABSTRACT

Furniture used in long term care facilities does not adequately address the needs of the ambulatory elderly. Poor ergonomics, unstable foundations, and weak structural members cause accidents. A wooden medium duration chair has been developed to address needs of these users. Features of the Autumn Chair allow for easier ingress and egress to the chair. A large footprint to the legs prevents tipping. The furniture is designed to tolerate high levels of physical abuse, whether in a long term care facility or in residential use.

BACKGROUND

A component of the Center's mission is to develop products that aid and assist in the activities of people with various levels of physical disability. The Center's Director has specialized in gerontological issues for over twenty years. Experience in this field has demonstrated that seating surfaces in care facilities do not address the needs of the ambulatory elderly. An opportunity arose that allowed the speculative development of a wooden chair that would address these seating issues.

STATEMENT OF PROBLEM

The ambulatory elderly have widely ranging levels of mobility, strength, and stability. Elderly users are generally smaller in stature (Pheasant, 1996) and have reduced leg strength. There is a tendency to use tables and chairs as support and balance structures when moving through a room. If the furniture has inadequate stability, it can tip causing falls and serious bodily harm.

Ingress and egress from chairs can be quite difficult, as many people use their arms to compensate for reduced leg strength. If the pushing force of the arms is not directed downward, the chair can slide away from the user as they stand. Armrests on medium to long duration seating can cause radial nerve pinch points at the elbow, resulting in numbness of the arm. Similarly, if the seat height is too great, numbness will occur in the lower legs.

For persons with hemiplegia, it is critical that a chair has the necessary structure to allow users to lift themselves with one hand out of the chair. This requires that the chair have ample strength and rigidity to absorb one-sided forces on a routine basis, with minimal flexion and without tipping over.

A thorough search for products to accommodate these needs was performed, with no satisfactory results. Several chairs were found that addressed certain stability or height issues. However, none were able to address all the ergonomic problems to create a complete solution.

APPROACH

One of the main requirements of a chair is stability. The legs of the wooden Autumn Chair create a large footprint on the floor (23" wide x 26" front to back). With a 16" deep seating surface centered front to back on the 26" footprint, the chair will not easily tip over (Figure 1). The front edge of the seat is 16" above the floor, 1 to 2" lower than typical seating (Koncelik, 1996). This allows users of smaller stature to sit comfortably in the chair with their feet flat on the floor, preventing pinched nerves on the back of the knees. The seat is reclined at an angle of 7 degrees, and deeply contoured for load distribution on the seat pan. The slatted seat back has an integral lumbar support (Lueder, 1994) and is made from 1" thick wood for strength. The chair is designed without a seat cushion, so that it can be easily sanitized in environments with multiple users

The armrests extend 4" beyond the leading edge of the seat, which performs several functions (Figure 2). People with dementia utilize the extended armrests to provide hand holds and guide themselves into the chair, reducing falls and injury. To help in egress, the armrests have contoured ends to provide grasping points when using the arms to help lift the body into a standing position. The extended armrests help to keep the center of gravity of the person aligned over the hands and feet, providing increased balance (Figure 3). Additionally, the armrests dip down in back to relieve radial nerve pressure at the elbow (Koncelik, 1996).

Figure 1.

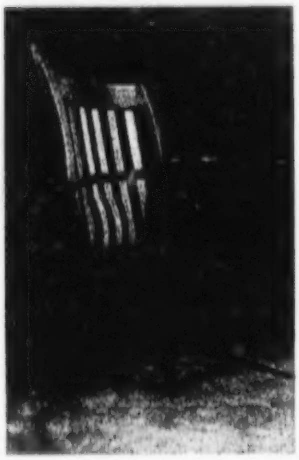


Figure 2.

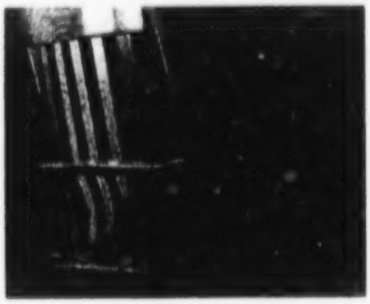
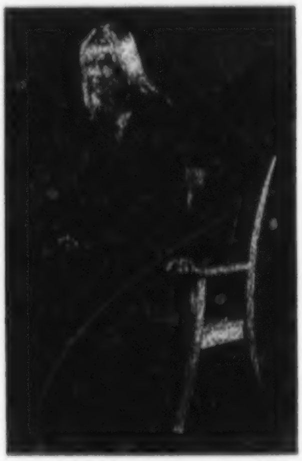


Figure 3.



EVALUATION

Testing on the Autumn chair has been performed in-house utilizing a wide ranging sampling of users. The 20 users encompassed male and female, age range from 30-58 years. The smallest tester was a early 40's, 40th % female and the largest was a late 50's, 97th % male. The chair design was decidedly the most comfortable for the smaller users in the study as predicted by the research of the intended user population. The taller users found the most comfort by projecting the feet forward to allow more body weight to be carried by the legs. Based on user comment, the lumbar support in the slats was reduced in size. The armrest end angle was changed to better accommodate the user's grip with entering and exiting the chair. As expected, several users indicated that a cushion would be a nice option for the chair. Due to sanitation concerns, a cushion would have to be provided by the end user.

DISCUSSION

Future long term testing will be undertaken after a short manufacturing run is completed. The chairs were designed for production by computer controlled woodworking machinery, allowing for on-the-fly changes as the design evolves. The initial prototype was constructed of pine for cost concerns. Two additional prototypes have been hand-made of oak to judge opinion on material selection. Additional woods will be investigated once production begins.

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AESTHETIC EVALUATION OF A FORCE SENSOR BY POWER WHEELCHAIR USERS

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ABSTRACT

Ten subjects participated in a clinical study on the use of a force sensor (FS) for driving a power wheelchair (PWC). Subjects compared the FS to their usual access device, a position-sensing joystick (PS). After finishing the study, each subject completed a questionnaire to assess their impressions on the aesthetic value of the FS. This paper describes the study and presents a brief overview of the responses to the questionnaire.

Despite its novelty, most subjects preferred the FS over their usual access device. Subjects also identified deficiencies and recommended improvements. Results warrant further investigation of force sensing technology for PWC control.

BACKGROUND

For many individuals, the ability to control a PWC independently has a tremendous impact on quality of life. A wide range of devices are available to enable many people to drive PWCs independently.[1] Unfortunately, many people with severe physical impairments still find it difficult or impossible to use existing devices. Previous investigators have studied manual transduction by people with disabilities,[2,3,4,5] but little work has been done on the use of FSs for PWC control.[6]

RATIONALE

This study aims to provide a proportional control alternative that requires virtually no range of motion by the user. An isometric FS is fundamentally different than existing devices which are primarily position sensors. A FS may help to harness the unique abilities of certain individuals. Someone with a high level spinal cord injury may use a FS for chin control. An individual with cerebral palsy, with strong spasms that will break conventional joysticks, may be able to use of FS for PWC control. We believe that this technology may also address the needs of individuals with multiple sclerosis, muscular dystrophy, tremors, and other conditions.

A digital force-sensor has been designed to interface via a microprocessor to a Quickie P300. This prototype device served as a clinical tool used to investigate force-sensing technology for PWC control. The objective was to allow PWC users to evaluate the FS after driving the Quickie P300 using both the FS and a PS. Because these individuals have many years of PWC experience, their opinions about the force sensor are quite valuable.

METHODS

Each subject used a PWC as their primary means of mobility, and each used a conventional, position-sensing joystick to control their PWC. Subjects were from 32 to 63 years old (average 47, SD 10 years), and their PWC experience ranged from 4 to 20 years (average 10, SD 6 years).

Seven subjects had spinal cord injury/dysfunction (level C4-6), two had multiple sclerosis, and one had strokes.

Each subject completed clinical trials that consisted of computerized tracking and actual driving, using both the FS and the PS. Both devices had similar enclosures so that both appeared the same. Also, both devices had the same handle, a rigid knob that was approximately 2 cm in diameter. Each subject used both devices with either their left or right hand, according to their preference. Before each test, a device was assigned randomly. The total time to complete the study was approximately four hours, and subjects actually spent about 45 minutes using each sensor.

EVALUATION

After finishing the study, each subject was asked to complete a questionnaire that included the following:

1) Rate each device, on a scale of 1 (poor) to 5 (excellent), in terms of ease of use, maneuverability, chair control, acceleration, and comfort.
2) Evaluate your physical and psychological experience in terms of fatigue, soreness, frustration, and lack of control.
3) Which device would you prefer for driving a PWC?
4) Suggest improvements to the force sensor.

RESULTS

All but one subject completed computerized tracking, and all ten completed the driving protocol. Table 1 lists the group averages of the responses to question 1) for the FS and the PS.

Table 1. Group Averages of Subject Rating for Force Sensor and Position Sensor

Category	**FS (SD)**	**PS (SD)**
Ease of use	4.7 (0.5)	3.9 (1.2)
Maneuverability	4.4 (0.7)	3.8 (1.2)
Chair control	4.5 (1.1)	3.9 (1.0)
Acceleration	4.7 (0.7)	4.0 (0.8)
Comfort	4.5 (0.7)	4.1 (1.1)
Overall	4.6 (0.7)	3.9 (1.0)

For all general impressions, the average score for the FS exceeded that of the PS. Two-tailed, paired t-tests of the two groups provided a statistical comparison of the significance of the differences ($p<0.05$). As a group, subjects rated the FS significantly better in terms of ease of use and acceleration. The other categories showed no significant difference. Eight subjects preferred the FS over the PS, and one subject had no preference. Only one subject preferred the PS, primarily because he was more familiar with his joystick.

Subjects provided valuable suggestions for improving the FS. Four subjects recommended changes to the sensitivity of the FS, including different sensitivities in the forward/backward and left/right directions. Three subjects recommended changing the shape of the handle.

Subjects had very limited responses to question (2), indicating that such a vague question provided limited feedback. Several subjects noted frustration while driving backward, perhaps attributed to the protocol and not the access device; all subjects had limited trunk and neck mobility.

DISCUSSION

Response of the questionnaires generally indicated that the FS was more aesthetically pleasing than the conventional joystick. The positive evaluation about the FS occurred despite the fact that all subjects used PS devices for daily PWC control. Within a short period of time, subjects evaluated the FS above their conventional access device.

Three of the subjects wanted more adjustability in the position of the FS. Although this FS provided substantial adjustment, future designs should include a wider range of securement positions. Several subjects expressed discomfort with the rectangular seating system of the Quickie P300; future studies should provide tilt and recline features. Seating issues become increasingly important with more severe impairments.

Software adjustments will accommodate the desire of subjects to change the sensitivity. In particular, changes in the control program will decrease the sensitivity independently in the forward/backward and left/right directions. Use of cruise-control features, implemented via software, will help to reduce subject fatigue.

A modular handle design will allow handle shape to be changed mechanically.

CONCLUSION

The ultimate goal is to provide an alternative access device for individuals who find it difficult or impossible to control a PWC with conventional devices. The subjects who participated in this study were regular PWC users; hand use of conventional PS's is at least sufficient. Their positive evaluation of the FS indicates that it may also help people who have more restricted capabilities.

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FRONTAL IMPACT FORCES ASSOCIATED WITH POWERED WHEELCHAIRS

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ABSTRACT

Persons in powered wheelchairs may engage in active lifestyles where wheelchair contact with the surroundings is inevitable. Force-time data were measured for 26 frontal collisions involving a wheelchair with a simulated occupant having a combined weight between 165 and 315 lbs. The wheelchair was rolled down a ramp into an instrumented crash barrier at velocities between 5.53 and 10.20 ft./sec. (nominally 4-7 mph). Peak forces varied between 207 and 470 lbs. These data could be used to design energy absorbing systems to protect the occupant, wheelchair components and the surroundings.

BACKGROUND

Persons in powered wheelchairs are adopting more active life styles that increasingly include recreation and leisure activities. Children and young adults may utilize their wheelchairs in sports, such as football and soccer, where wheelchair contact is inevitable. A powered wheelchair has a maximum speed of about 7 mph (10.27 ft./sec). When a wheelchair traveling at this speed impacts either a stationary object or another wheelchair, large forces occur over a short time interval and a considerable amount of kinetic energy must be dissipated. Damage to the footrests can occur and occasionally the occupant's feet may also be injured. Powered wheelchairs can also cause significant damage to physical surroundings, such as doors and walls. Footboxes can provide protection for the occupant's feet, but may actually increase the potential for damage and injury in a collision with another wheelchair not similarly equipped. Unprotected, rigid footboxes may also increase the level of damage to the surroundings.

The ANSI/RESNA footrest impact load test (1) specifies that the footrests must survive a 3.28 ft./sec. (1.0 m/s) impact at a 45° angle. Velocities far in excess of this value are routinely encountered in sports events. While energy absorbing suspension components are currently available, there have been few attempts to incorporate energy absorbing systems or bumpers on wheelchairs. We are aware of prototype footrest suspension systems that have incorporated shock absorbers and/or energy dissipating materials. The performance of these prototypes has been marginal, since they were not designed using actual collision data. The lack of information on the dynamics of impact is a significant impediment to the design of such systems.

RESEARCH QUESTION

There is a need to develop force-time data for the frontal impact of powered wheelchairs to support the design of energy absorbing systems for wheelchairs that can protect the footrests, the occupant and the surroundings.

METHOD

A 165 lb. powered wheelchair was rolled down a ramp, across a level floor and into an instrumented impact barrier. Sandbags were added to the wheelchair in 50 lb. increments to simulate the weight of the occupant. Adjusting the starting position on the ramp allowed the impact velocity to be varied. Two photoelectric sensors placed in front of the barrier measured the velocity to within +/- 0.01 ft./sec. The impact barrier was constructed using steel beams and instrumented with strain gauges. The barrier was calibrated in a testing machine and demonstrated a linear force-voltage relationship (r^2=0.99) within the range of 0-500 lbs. The force-time relationship is affected by the stiffness of the system with which the wheelchair collides. A 0.5-inch thick piece of pressboard was placed between the barrier and a brick wall to simulate the object being impacted. Data were collected at 1000 Hz using a PC and exported to a spreadsheet. Force-time data were recorded in 26 experiments for a 165-315 lb. wheelchair system impacting the barrier at velocities between 5.53 and 10.20 ft./sec. A storage oscilloscope was used to collect more refined force data in a limited number of additional tests.

RESULTS

Figure 1 shows a typical force-time response recorded by the PC. The step-like response is due to a software limitation that caused the force to be recorded in threshold increments of 63.8 lbs. Data recorded from experiments using the storage oscilloscope showed a rapid linear loading curve followed by a more gradual unloading curve that could be approximated by straight line segments. A continuous force-time curve was created from the step data using straight line segments (Figure 1). According to Newton's laws, the linear impulse is equal to the change in linear momentum (2). The linear impulse is the area under the force-time plot, while the change in linear momentum is mass of the wheelchair system times the initial velocity. The linear impulse calculated from the force-time curve was compared to value predicted from the change in linear momentum. The average error for the 26 frontal impacts was 11.6%. Some damage to the wheelchair was noted in the 7 mph collisions. Peak forces estimated from the modified curves varied between 207 and 470 lbs. Collision times varied between 0.280 and 0.594 seconds. Within the range of parameters tested, the peak force increased with increasing velocity and occupant weight (Figure 2).

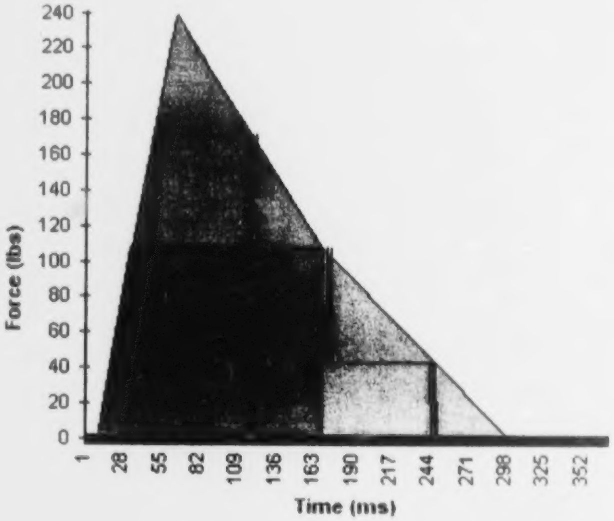

Figure 1. Force-time impact data for an unloaded 165 lb wheelchair traveling at 5.82 ft./sec. Straight lines were used to connect the discrete steps. The linear impulse is equal to the shaded area.

DISCUSSION

The advent of more active lifestyles, particularly among teenagers and young adults, has increased the possibility of collisions between powered wheelchairs and other objects. The footrests are usually suspended in a cantilever manner from the chair frame and thus are particularly vulnerable to collision damage.

For the unoccupied wheelchair, a 4mph (5.87 ft./sec.) collision generated a peak force of approximately 200 lbs. and it was necessary to stiffen the footrests to avoid permanent deformation.

A wheelchair occupied by a 150 lb. person and traveling at 4 mph would generate a peak force of approximately 350 lbs. (Figure 2). Further stiffening of the footrests was necessary to conduct tests at 6 and 7 mph (8.80 and 10.27 ft./sec.). At these velocities, the stiffness of the test system clearly exceeded the stiffness of the commonly used footrest mounting systems.

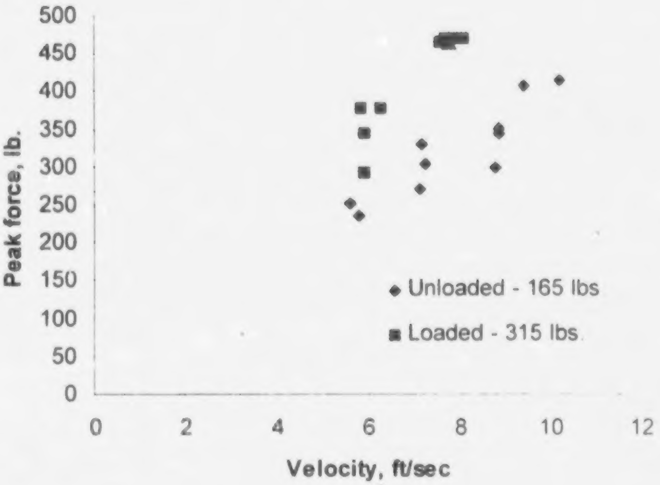

Figure 2. Peak force as a function of velocity.

The weight of the occupant was simulated by attaching sandbags to the seat and back of the wheelchair. This placed the center of mass attributed to the occupant lower and slightly rearward of its actual location. Modeling the mass of the occupant could be improved by using an ANSI/RESNA test dummy (3). The most significant limitation of the study involved the lack sensitivity in measuring the impact force. Our software/hardware system was capable of sampling at a high frequency (1000 Hz), but was only able to resolve the impact force into steps of 63.8 lbs. Thus, it was necessary to develop continuous force-time curves from discrete experimental data. The accuracy of this method was established by conducting an impulse momentum analysis of each test and by using a storage oscilloscope to obtain continuous time data from additional tests.

Past studies of impact loading on wheelchair components have focussed on using accelerometers or strain gages mounted on the wheelchair (4). However, in the case of frontal impact it appears to be more efficient to instrument the impact barrier rather than the chair. This study represents a first step toward quantifying the design requirements for energy absorbing systems for powered wheelchairs that would protect the occupant, the wheelchair components and the surroundings. Real collisions are likely to contain both frontal and lateral components. Further studies involving lateral impacts should be performed.

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ANALYSIS OF WHOLE-BODY VIBRATION DURING MANUAL WHEELCHAIR PROPULSION USING ISO STANDARD 2631

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ABSTRACT

The emphasis of manual wheelchair testing has primarily been related to structural testing of the wheelchair rather than examining the amount of vibration an individual experiences during manual wheelchair propulsion. The purpose of this paper is to compare the whole-body vibrations associated with manual wheelchair propulsion to the ISO standard 2631/1. Wheelchair seat vibration data was recorded as 10 individuals with SCI traversed 8 obstacles. The intensity for over a quarter of the frequencies, including the resonant frequencies of humans (4 to 8 Hz), are above the fatigue-decreased proficiency boundary for 25 minutes of exposure. Therefore, adaptations need to be implemented to the wheelchair system in order to reduce the amount of whole-body vibration an individual experiences thereby reducing the individuals susceptibility to a secondary injury.

INTRODUCTION

The emphasis of manual wheelchair testing has primarily been related to structural testing of the wheelchair, and it's components using ANSI/RESNA standards. Until recently, quantitative data has not been collected in regards to the development of standards to address dynamic response issues of individuals who use manual wheelchairs. Furthermore, the only standards which are available for determining the intensity of vibration which causes discomfort is based on research collected using individuals without a spinal cord injury (SCI) [1]. The standards which are recommended for individuals without SCI are constantly being questioned and revised [2]. The standards presented by the International Organization for Standardization for whole-body vibration in ISO 2631/1 may or may not be appropriate for comparison to individuals with SCI [3]. Therefore, the vibrations an individual with SCI experiences while propelling a manual wheelchair over obstacles during activities of daily living need to be examined for two reasons. One is to determine if the vibrations an individual experiences exceed the fatigue-decreased proficiency boundary defined in ISO 2631/1. The second is to investigate if the ISO standards, which are based on data collected from individuals without SCI, apply to individuals with SCI. If not, are there other parameters and/ or standards which need to be developed in order to protect individuals with SCI from secondary injuries associated with vibrations. The purpose of this paper is to compare the whole-body vibrations associated with manual wheelchair propulsion to the ISO standard 2631/1.

METHODS

A triaxial accelerometer (Analog Devices ADXL05, ±4g) was mounted on the seat of the wheelchair to measure vibration induced by the simulated activities of daily living obstacles in three orthogonal directions. The acceleration signals were sampled at 200 Hz via a battery powered custom-designed data acquisition system based on a Motorola microcontroller (MC68HC11A1) with 8-bit A/D converter [4].

A total of 10 individuals with SCI who used a manual wheelchair as their main mode of mobility propelled an instrumented wheelchair to negotiate 8 obstacles at least three times. Two subjects performed four trials and one performed five trials, producing a total of 34 trials. The subject used his or her own cushion for all trials. Either a Quickie II wheelchair or a Kuschal Champion 1000 wheelchair was instrumented. The eight obstacles consisted of square tiles used to make dimple strip guidance markers for the visually impaired, a piece of light-industrial carpet, a simulated door threshold, a ramp, a curb drop, rumble strips and finally, three sinusoidal bumps of varying height. The instant the front casters contacted an obstacle and the rear wheels cleared the obstacle were recorded.

The Root Mean Square of the wheelchair vibration signal in the vertical (z) direction was calculated based on the ISO 2631/1 for the wheelchair traversing all the obstacles [3]. A sample trial of the vertical acceleration is shown in Figure 1. The results for each trial were averaged across the 34 trials to show the average intensity of the vibrations experienced by the wheelchair users at the frequencies described by ISO 2631/1.

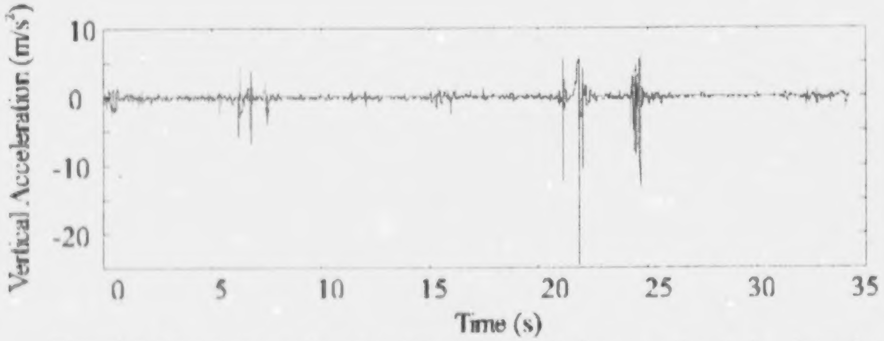

Figure 1. Vertical acceleration for a single trial across the eight obstacles.

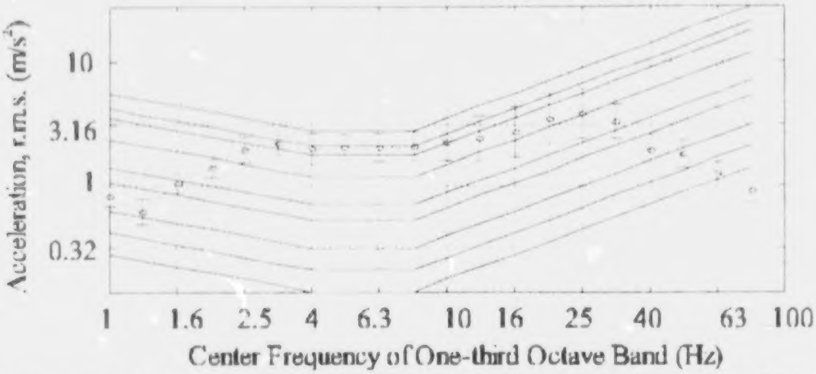

Figure 2: Vertical whole-body vibration mean and standard deviation (o) for 34 trials with fatigue-decreased proficiency boundary. The boundaries from top to bottom are 1 min, 16 min, 25 min, 1 hr, 2.5 hr, 4 hr, 8 hr, 16 hr, and 24 hr.

RESULTS

The mean and standard deviations of the RMS values of the wheelchair vibrations induced by the simulated activities of daily living course are shown in Figure 2. Also, the fatigue-decreased proficiency boundary, as described in ISO 2631/1, is superimposed on Figure 2. The mean intensity values exceed the fatigue-decreased proficiency boundary for 25 min from 3.15 Hz to 10 Hz, and exceed the boundary for 1 hour at 2.5 Hz and again from 12.5 Hz to 25 Hz. The mean and standard deviation of the length of a trial was 26.7 ± 5 s.

DISCUSSION

In this paper, the vibrations experienced by individuals with SCI who use a manual wheelchair on a daily basis, were quantitatively analyzed by measuring the accelerations of the wheelchair seat. The intensity of the vibration at different frequencies was calculated based on ISO 2631/1 and then compared to the fatigue-decreased proficiency boundaries. The intensity for over a quarter of the frequencies, including those associated with the most sensitive frequencies for humans (4 to 8 Hz) [3], are above the boundary for 25 minutes of exposure. If the data collected were assumed to be representative of a half-hour excursion (e.g. to a store) the individual would definitely experience reduced comfort as described in ISO 2631/1. They would also typically experience fatigue which can be "regarded as carrying a significant risk of impaired working efficiency" [3]. Therefore, adaptations need to be implemented to the wheelchair system in order to reduce the amount of whole-body vibration an individual experiences and reduce the individuals susceptibility to a secondary injury. This may take the form of redesigning the wheelchair by adding springs and dampeners to the wheelchair, changing the material used to construct the frame or changing the configuration of the frame. Also, different combinations of cushions and back supports may be added to the seating system in order to reduce the vibrations.

Future investigations will examine activities of daily living trials of longer duration, as well as community-based trials, where data will be collected on the order of hours rather than minutes. Also, this data can be correlated to qualitative surveys completed by the subjects after the trials to determine their comfort, which can be used in the development of standards for individuals with SCI. Finally, as suggested by Lundstrom et al [2], other parameters, such as energy, may be better descriptors of the vibration absorbed by the individual and should be used to set up standards rather than acceleration alone.

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PORTABLE DEVICES TO MEASURE SURFACE FIRMNESS AND STABILITY

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ABSTRACT

Research has been conducted to design and develop portable devices and test procedures to objectively measure the firmness and stability of indoor and outdoor surfaces. The goal of this project was to develop and evaluate two new prototype devices for measuring surface firmness and stability. Each device was evaluated on six test surfaces and measurements obtained with the portable devices were compared to wheelchair work per meter values.

BACKGROUND

Physical characteristics of a surface affect the level of accessibility for people with and without disabilities. The Americans with Disabilities Act Accessibility Guidelines (ADAAG) require that ground and floor surfaces be stable, firm, and slip-resistant (1). However, ADAAG does not specify how the stability, firmness or slip-resistance of a surface should be measured.

STATEMENT OF THE PROBLEM

Currently there are no commercially available portable devices that can measure the firmness and stability of a spectrum of surfaces ranging from hard concrete to soft sand. Available devices are either extremely expensive, complicated and difficult to use, requiring significant knowledge and a substantial amount of time to test, or are simple devices that lack sufficient sensitivity to differentiate between surfaces, such as two different types of wood fiber. In addition, measurements obtained with the commercially available devices have not been correlated to the amount of work required to propel a wheelchair across the surface or the amount of energy required for a person to walk or wheel on a surface.

RATIONALE

A measurement method is needed which can economically and easily assess the firmness and stability of a wide spectrum of surfaces. The objectives of this project were to develop and test two new devices that could objectively measure the firmness and stability of surfaces, using a simple test procedure that did not require extensive knowledge, training or time.

DESIGN

The physical characteristics of a surface that affect its level of trafficability have been identified as: resistance to penetration, shear strength, slipperiness, water content, and presence of obstacles (2). The new prototype devices were designed to measure both resistance to penetration (firmness) and shear strength (stability). Both devices utilized digital linear encoders that interface with a laptop computer and a data acquisition system to record the measurements.

Rotational Penetrometer

The Rotational Penetrometer utilized an 8-inch pneumatic caster that rotates about its vertical axis. Forty-two pounds of force were applied to the wheel, and an initial measurement of the amount of displacement of the device into the surface was recorded. With the force still applied, the wheel was rotated through five 90 deg. rotations, with depth measures recorded after each 90 deg. displacement. These rotational measurements indicate the stability of the surface.

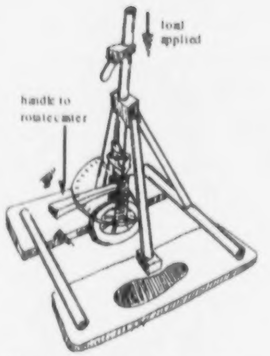

Figure 1. Rotational Penetrometer

Translational Penetrometer

The Translational Penetrometer had a carriage that traveled on linear bearings and allowed free travel in three axes. It utilized 42 lb. of downward force on a 6-inch solid wheelchair caster to assess the firmness of the surface. To measure the stability of the surface, it used 20 lb. of lateral force. Once the initial measurement of downward displacement was recorded, the lateral force was released and displacement on the surface measured. Then the carriage was moved forward, and measurements of depth and lateral displacement were taken every 2 inches, over a total distance of 16 inches.

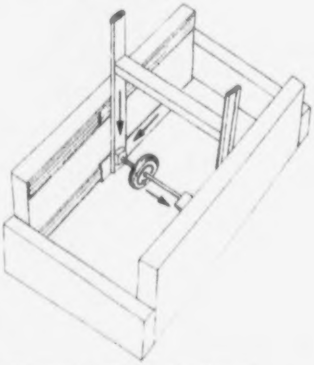

Figure 2. Translational Penetrometer

EVALUATION

The two portable devices were used to measure six test surfaces: smooth level concrete (CEME), crushed granite with stabilizer (RDOL), accessible carpet <0.5 in. level pile with no pad (ACAR), engineered wood fiber that passes ASTM PS 83 (EWFK), engineered wood fiber that fails ASTM PS 83 (EWFJ), and sand (SAND). Prior to each test the surfaces were leveled and compacted. To maintain a constant spring force, the surface had to be free of depressions greater than 0.75 inch. Five trials were taken with each device on each surface.

Work per meter values for wheelchair straight propulsion and turning were determined for five of the six test surfaces using the ASTM PS 83 test procedure (3) (Figure 1); values for sand were not obtained because the test procedure could not be performed.

The measurements obtained with each prototype device ranked the surfaces in the same order and in similar magnitude as the work per meter values (Figures 2 and 3). The Rotational Penetrometer values used in this analysis were taken at 360 degrees of rotation, which is where the greatest differentiation between the surfaces occurred. The correlation between the wheelchair work per meter values and the Rotational Penetrometer was significant ([R^2=0.992] for straight propulsion and [R^2=0.915] for turning). The measurements used for the Translational Penetrometer were the initial penetration into the surface, and the final lateral displacement. The Translational Penetrometer also had a significant linear correlation coefficient when comparing lateral displacement and turning using the wheelchair work per meter values (R^2=0.995).

DISCUSSION

Both of the devices performed well on the range of surfaces tested. Most notable was the ability to consistently differentiate between the two engineered wood fibers, one of which does not meet the requirements of ASTM PS 83, requiring more work than a 7% ramp and therefore considered to be not accessible under the ASTM standard.

A problem encountered with the Translational Penetrometer is that any contours on the surface can lead to an erroneous depth reading, which is why only the initial reading can be used.

The results of this study suggest that these two devices could potentially be used to predict the amount of work required to propel a wheelchair on level surfaces. Future research will include refining the devices, testing on more surfaces and determining the relationships between measurements obtained with the devices and wheelchair work per meter values. The devices will also need to be validated through comparisons with the metabolic energy required to negotiate the surface and perceived levels of difficulty.

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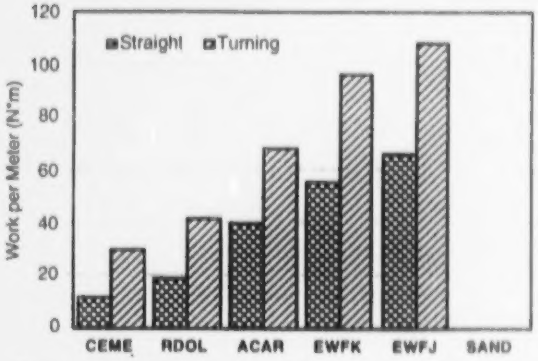

Figure 1. Wheelchair work per meter values

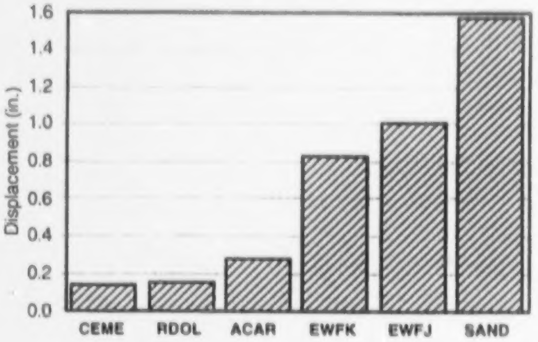

Figure 2. Rotational Penetrometer results

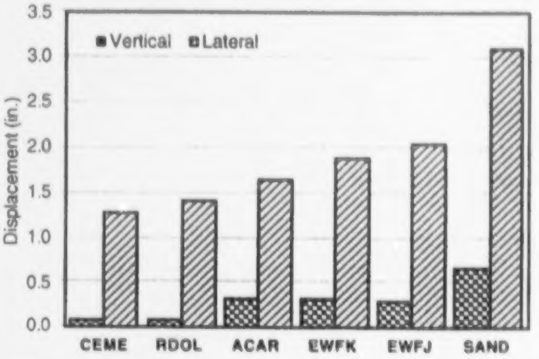

Figure 3. Translational Penetrometer results

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USER EVALUATIONS OF THREE LOW-IMPACT PUSHRIM DESIGNS

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ABSTRACT

One proposed approach to reduce the likelihood of developing upper extremity pain and injury in manual wheelchair users is the use of a low-impact pushrim. Low-impact pushrims incorporate flexibility between the wheel and the pushrim, which absorbs impact forces during propulsion. This study investigated the effects of three low-impact pushrim designs on users' perception of control, comfort, and effort after maneuvering across a test course. In general, when subjects perceived differences between low-impact pushrim concepts and a rigid pushrim, the results were negative, either due to decreased control and comfort, or increased effort required. The results of this study serve to provide a more defined set of design specifications for future low-impact pushrim concepts.

BACKGROUND

Wheelchair pushrim design has changed little since its inception. Pushrims provide wheelchair users with a very intuitive and effective mechanism by which to control and maneuver their wheelchairs. Despite these attributes, pushrim design is not without some fundamental problems.

Upper extremity (UE) pain and injury are common among manual wheelchair users (MWUs). In a study of 239 MWUs, Sie et al. found that 64% of paraplegics and 55% of quadriplegics experienced UE pain (1). The most common sites of UE pain were at the shoulder and wrist. This pain limits UE strength and range of motion, decreasing mobility and functionality and thus resulting in loss of independence.

In a study relating wheelchair propulsion biomechanics to upper extremity pain and injury, Robertson et al. identified impact loading of the UE (which occurs as the hand first contacts the pushrim during the beginning of the drive phase) as the probable injury mechanism (2). One proposed solution is the use of a low-impact pushrim (LIP), designed specifically to reduce impact forces.

RESEARCH QUESTION(S)

The basis of low-impact pushrim (LIP) design is to incorporate flexibility between the wheel and the pushrim. The use of a LIP may reduce the likelihood of developing UE pain and injury but it is unclear how it will affect users' ability to control and maneuver their wheelchair. Will the use of a LIP result in a loss of control or comfort, or an increase in effort required to maneuver the wheelchair? Is there an appropriate amount of flexibility such that a LIP does not adversely affect the user?

METHOD

Seven experienced MWUs volunteered and gave written consent to participate in this study. The subjects had a spinal cord injury at a level T-2 or below. The average number of years using a manual wheelchair was 15.3, ranging from 3 to 30 years.

The three low-impact pushrims utilized different interface mechanisms: rubber Shock Mount (SM), Extension Spring (EP), and Bungee Cord (BC). The load-deflection characteristics of the concepts are shown in Figure 1. The load was applied tangentially to the pushrim and the displacement of the rim with respect to the tire was measured in the direction of the applied load.

Subjects were asked to maneuver their own wheelchair across a test course using a rigid pushrim and then again with each of the LIP concepts. The test course consisted of a curved uphill path, a level sprint, a curved downhill path, a door threshold, a slalom course, a carpet, a wheelie, and a standard ramp. The LIP concepts were evaluated in a randomized order.

For the door threshold activity, subjects started with their rear wheels in contact with a 1.25 in. tall threshold and then in one push, rolled up and over it. The slalom and sprint activities were timed. Subjects were asked to achieve their best times for each trial. The carpet activity included a straight path, one 90-degree turn and one 180-degree turnaround. After each activity, subjects were asked about their perceived level of control, comfort, and effort when completing the task. Responses were then constrained to a comparison between the pushrim concept being used and the rigid pushrim, such that answers were either "more," "less," or "about the same." After completing all eight activities with each LIP concept, subjects were asked to rate its overall performance. Upon completion of the activities using all of the LIP concepts, subjects were asked to compare the concepts and give general feedback.

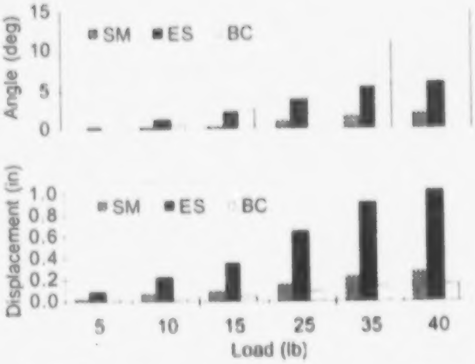

Figure 1. LIP load-deflection characteristics

RESULTS

All seven subjects were able to complete the test course using each of the LIP concepts. Subject responses to control, comfort, and effort questions for each of the individual activities are shown in Figures 2, 3, and 4, respectively. Subjects generally perceived to have less control using the LIP concepts as compared to the rigid pushrim (Figure 2). However, responses to the SM concept in particular indicate that there was very little perceived difference in control. Subjects generally perceived the LIP concepts to be less comfortable as compared to the rigid pushrim (Figure 3). However, there were noticeable improvements from the responses to control in the sprint, wheelie, ramp, and carpet activities. Again, as was the case for perceived control, specific responses to the SM concept indicate that there was very little

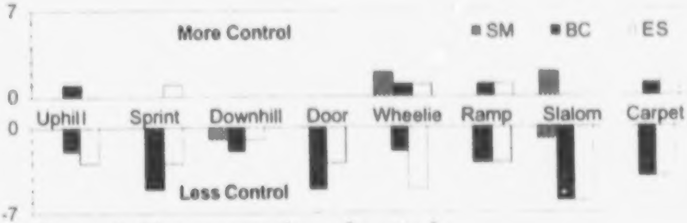

Figure 2. User perception of control

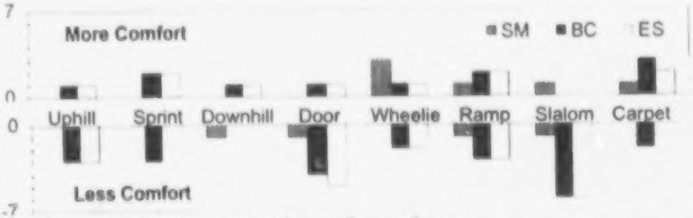

Figure 3. User perception of comfort

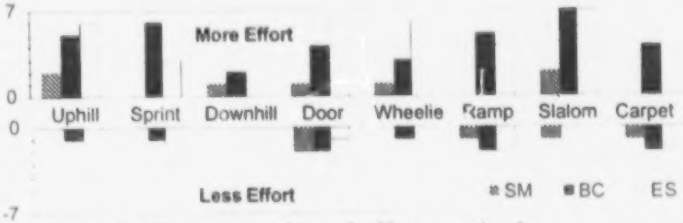

Figure 4. User perception of effort required

perceived difference in comfort. Subjects generally perceived to expend more effort using the LIP concepts as compared to the rigid pushrim (Figure 4). Several subjects perceived a decrease in effort for some selected activities. Similar to perceived control and comfort, specific responses to the SM concept indicate that there was very little perceived difference in effort. Subjects perceived little difference in their ability to maintain balance while using the LIP concepts to complete the activities.

Only one subject perceived the SM concept to reduce impact forces, whereas five of the subjects preferred it over the other concepts. Six subjects perceived the ES concept to reduce impact forces, but only two preferred it to the other concepts. Five subjects perceived a return of stored energy during the final stages of the push when using the ES and BC concepts. All seven subjects responded that they would use the SM concept while only one subject would use the ES and BC concepts. Four subjects responded that they would change their mind and use their least favorite concept if it was shown to reduce the likelihood of developing UE pain and injury. All of the subjects responded that they would want to use the LIP concepts for a longer period of time in order to more completely evaluate their performance.

DISCUSSION

In general, when subjects perceived differences between the low-impact pushrim (LIP) concepts and the rigid pushrim, the results were negative either due to decreased control and comfort, or increased effort required. The goal of LIP concepts is to reduce the likelihood of developing UE pain and injury due to impact forces during propulsion, but without reducing the existing level of functionality or performance. This study has shown that a threshold of pushrim displacement may exist, defined by the SM concept, at which users do not perceive losses in control, comfort, or effort while still providing some impact force reduction. The results of this study serve to provide a more defined set of design specifications for future LIP concepts. Further work will investigate the effects of these LIP concepts on propulsion impact forces, kinematics and efficiency.

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MECHANICAL EFFICIENCY OF LOW-IMPACT PUSHRIMS

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ABSTRACT

Upper extremity pain and injury are common among manual wheelchair users. One approach to reducing the likelihood of injury is the use of a low-impact or flexible-interface pushrim. This study investigated the effects of a low-impact pushrim on mechanical efficiency. Three low-impact pushrim concepts were compared to a standard rigid pushrim. Propulsion work requirements were measured using each of the pushrims to negotiate four ramp grades ranging from 6.3% to 10%. The average relative mechanical efficiencies ranged from 94.9% to 97.3% for the three concepts. The results suggest that the use of low-impact pushrims may not result in a significant decrease in mechanical efficiency.

BACKGROUND

The mechanical efficiency of manual wheelchair propulsion has been extensively studied (1,2,3). These studies have shown that the metabolic energy expended during propulsion is significantly higher than the mechanical energy output from the wheelchair. Many of these losses result from the recovery phase of the push cycle. Net mechanical efficiency has been found to rarely exceed 13% and gross efficiency to rarely exceed 11% (3). In an effort to improve mechanical efficiency, several studies have investigated factors such as seat position and wheelchair set-up (1,2).

Wheelchair propulsion is not an ergonomically optimal activity and less efficient than ambulation. The upper extremities are not designed to withstand repetitive, high impact loading, and therefore, wheelchair users frequently experience upper extremity pain and injuries. In a study of 239 manual wheelchair users, Sie et al. found that 64% of paraplegics and 55% of quadriplegics experienced UE pain (4). The most common sites of UE pain were at the shoulder and wrist. This pain limits UE strength and range of motion, decreasing mobility and functionality and thus resulting in loss of independence.

In a study relating wheelchair propulsion biomechanics to upper extremity pain and injury, Robertson et al. identified impact loading of the UE (which occurs as the hand first contacts the pushrim during the beginning of the drive phase) as the probable injury mechanism (5). One proposed solution is the use of a low-impact pushrim designed specifically to reduce impact forces.

RESEARCH QUESTION(S)

The basis of the low-impact pushrim design is to incorporate flexibility between the wheel and the pushrim. The use of a low-impact pushrim may reduce the potential for developing UE pain and injury, but it is unclear how this flexibility will effect mechanical efficiency. Will the use of a low-impact pushrim result in a reduction in mechanical efficiency, and if so, is there an optimal amount of flexibility that minimizes the adverse effects while still reducing the high impact forces?

METHOD

Three different low-impact pushrim concepts as well as a standard rigid pushrim were mounted onto a wheelchair and used to propel up four different ramp grades: 6.3%, 7.1%, 8.3%, and 10% (1:16, 1:14, 1:12 and 1:10, respectively). During propulsion, the torque applied to the pushrim was

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measured. The work required for propulsion was a product of the applied torque and the resulting angular displacement of the wheel. Five trials with each low-impact pushrim concept were performed for each ramp grade.

The three low-impact pushrims utilized different interface mechanisms: rubber Shock Mount (SM), Extension Spring (EP), and Bungee Cord (BC). The load-deflection characteristics of the concepts are shown in Figure 1. The load was applied tangentially to the pushrim and the displacement was measured in the direction of the applied load.

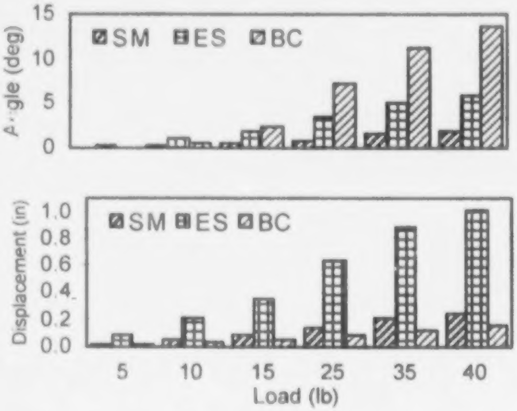

Figure 1. Load-deflection characteristics

A 16 in. width rehab wheelchair (Quickie 2 by Sunrise Medical) with 24 in. pneumatic rear tires was used as the test wheelchair. A $\text{SMART}^{\text{Wheel}}$ (6) was mounted onto the wheelchair and used to measure the torque applied during propulsion. The wheelchair weight with 8 in. pneumatic casters was 34 lb. A laptop computer and an external battery pack were mounted onto the wheelchair. The total weight of the wheelchair with the computer and power source was 54 lb. The wheelchair rider weighed 193 lb. and was seated such that when statically measured, the front-to-rear weight distribution was 40/60 %.

The wheelchair was propelled 2 (+0.2, -0.0) m in 7 (+/- 0.25) seconds using four uniform pushes. Torque applied to the pushrim was recorded at 240 Hz. The average torque for each trial was found by numerically integrating the torque as a function of time and then dividing by the total trial time. Propulsion work was determined by multiplying the average torque by the total angular displacement of the rear wheel. The average work per meter value was calculated by discarding the highest and lowest values and averaging the remaining three. Relative mechanical efficiency was determined by dividing the average propulsion work required using the low-impact pushrim by that required using the rigid pushrim.

RESULTS

The average mechanical efficiencies for the three low-impact pushrim concepts across the four ramp grades ranged from 94.9% to 97.3% (Table 1). The minimum mechanical efficiency was 89.9% with concept BC on the 6.3% grade ramp and the maximum was 99.1% with concept ES on the 10% grade ramp.

Concept SM had the highest average efficiency (97%) with the least variation (2.4%). Concept BC had the lowest average efficiency (94.9%) and the greatest variation (8.2%). For increasing grades, each of the concepts generally resulted in an increase in efficiency.

Table 1. Mechanical efficiencies of three low-impact pushrim concepts

Ramp Grade	SM	ES	BC
6.3% (1:16)	95.3%	92.7%	89.9%
7.1% (1:14)	97.5%	96.9%	95.6%
8.3% (1:12)	98.5%	96.2%	96.0%
10% (1:10)	97.7%	99.1%	98.1%
Average	97.3%	96.2%	94.9%

DISCUSSION

The goal of low-impact pushrims is to reduce impact forces during manual wheelchair propulsion, and therefore reduce the likelihood of UE pain and injury. By the nature of their design, some losses in efficiency are expected. The results of this study suggest that the use of low-impact pushrims need not result in excessive losses in mechanical efficiency. The angular displacement characteristics of the ES concept were essentially an average of the SM and BC concepts, a pattern that was also evident in the mechanical efficiency results. However, the ES concept produced translational displacements that were significantly greater than the SM or BC concepts. This indicated that angular load displacement characteristics appear to be a stronger predictor of changes in mechanical efficiency than translational displacement characteristics.

Increases in mechanical efficiency with increasing ramp grade may be due in part to the nearly constant amount of work required to displace the pushrim during the initial impact. As the amount of work required to negotiate the ramp increased, and the work expended in impact absorption remained constant, the ratio of the two quantities decreased. Since this ratio represents losses in efficiency and is decreasing, the result is an effective increase in mechanical efficiency.

This study was a preliminary effort to understand the effects of low-impact pushrims on mechanical efficiency and is not a comprehensive evaluation. Limitations of this study include use of only a single test subject and exclusion of ramp grades of less than 6.3%. Future work will address these limitations as well as investigate the effects on metabolic efficiency.

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ACKNOWLEDGMENTS

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DETERMINATION OF GENERIC SEAT INTERFACE SHAPES BY CLUSTER ANALYSIS

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ABSTRACT

The purpose of the paper was to determine if there exists more than one typical or generic shape pattern of the buttock-cushion interface for disabled people, by analyzing the dissimilarity in geometrical shape descriptors or parameters. The group of subjects were composed of 30 elderly people (age 65 years or older) and the shapes of the buttock-cushion interfaces were measured by the ESS (2). Four distinct generic shapes were identified by means of the cluster analysis method. The results suggested that the generic shapes were mainly characterized by the symmetry of the shapes. The determination of elderly people's seat interface shapes into four different functional clusters may lead to a more comprehensive understanding of the support surface shapes.

INTRODUCTION

The complexity of cushion design is reflected by a proliferation of studies related to rehabilitation, prevention of pressure ulcers and sitting comfort. It is well known that no single cushion provided optimal results for all users, because of the individual mechanical responses at the body-seat interface level (4). The mechanical properties of cushions combined with tissue tone and underlying skeletal structures determine the resultant buttock-cushion interface shape. Seat interface shape measurements can be used to evaluate the buttock-cushion interface. Sprigle et al. (4) distinguished different shape contours between able-bodied and disabled people. The support surface shapes of disabled subjects show significant variability and some of them depart significantly from others. This has raised the issue of the existence of more than a single generic shape in support surfaces. Our purpose is to develop a feasible method for determining a certain number of generic surface shapes that are suitable for different groups of users. We hypothesized in this paper that more than one generic shape can be found by grouping the interface shapes of elderly subjects into different clusters. The mean shape of the cluster can be considered as the generic shape for the corresponding cluster.

METHODOLOGY

This study is based on the data gathered by the Seating and Soft Tissue Biomechanics Laboratory at the University of Pittsburgh. Thirty elderly people over the age of 65 (81.6±8.4 years) participated in the data collection. Their average weight was 64.6±15.7 kg. Each subject sat on an electronic shape sensor (ESS) and the resulting shape of the support surface was recorded. The details about this process are presented in Brienza et al. (1)

Many measurements could be defined and/or selected to classify the shapes of support surface. A set of preliminary measurements was developed to describe the geometrical characteristics of the seating interface shapes (2). From this study, other measurements were added to form a list of 8310 measurements for analysis of each shape. This list included 2323 measurements (23 geometrical parameters x 101 medial-lateral cross sectional curves along the surface) which characterized the lateral curve shapes, 1414 measurements (14 parameters x 101 anterior-posterior cross sectional curves) which characterized the longitudinal curve shapes, 404 measurements (4 parameters x 101 top-view horizontal contours) which described the transverse contour shapes and 14 parameters which characterized the whole 3-D seat interface shape. Principal component analysis was then performed on this list in order to reduce the number of measurements based on extreme distribution and redundancy. This yielded to a list of 56 measurements which revealed the dominant geometrical characteristics of the shape.

Cluster analysis was chosen in the present study as the multivariate procedure for detecting natural grouping in the input data. The 3-D shapes were arranged into clusters. The Ward's hierarchical method (5) for the cluster analysis procedure (STATISTICA package) was used in an attempt to develop a hierarchical tree (dendrogram), where the same observation (shapes, in our case) was not allowed to appear in more than one cluster. The basis for a cluster analysis is formed by calculating the degree of dissimilarity among the relevant variables (measurements, in our case) for the different observations. This can be done in several ways. In this study, the Pearson Product Moment was chosen as the measure of dissimilarity (the larger the distance between two shapes, the less they are alike). The differences between fusion levels in the dendrogram were examined in order to determine the number of clusters. Large changes are taken to indicate a particular number of clusters.

RESULTS

The dendrogram (Fig 1) obtained from the cluster analysis depicts large clusters characterizing loose associations of shape patterns, and smaller clusters that define more closely related patterns. At a small distance level, there are still many clusters with only a few subjects in each; at a larger distance level, the number of clusters decreases, but the number of subjects increases. At the bottom of Fig. 1 the number of clusters are shown for four distance levels. Depending on the distance level of clustering, we can identify two to six clusters. The first dichotomy (A) divides the original 30 shapes into two clusters of 25 shapes and 5 shapes, separating the shapes which have lower left lobes from the rest of the group. The larger cluster is hierarchically subdivided into two clusters of 6 and 19 shapes, at the second dichotomy (B). At the distance level of 0.2, four clusters (C1-C4) can be identified. The large distances between these four clusters can be taken as evidence for considering the four-cluster division as most relevant. The mean shapes for each cluster are displayed in Fig. 2. Each shape has two lobes. The width (W) and height (H) between these two lobes are shown in Fig 2. Cluster C1 contains six shapes of which the right lobe is lower than the left one. Generally, the ten shapes in C2 and the nine shapes in C3 are more symmetrical, but the widths (W) between the lobes of the shapes in cluster C2 are smaller than

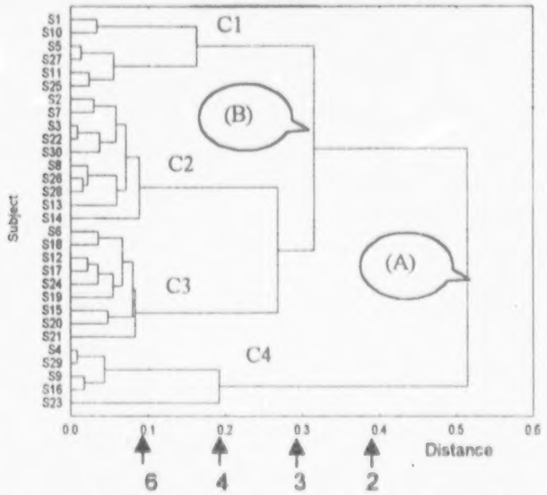
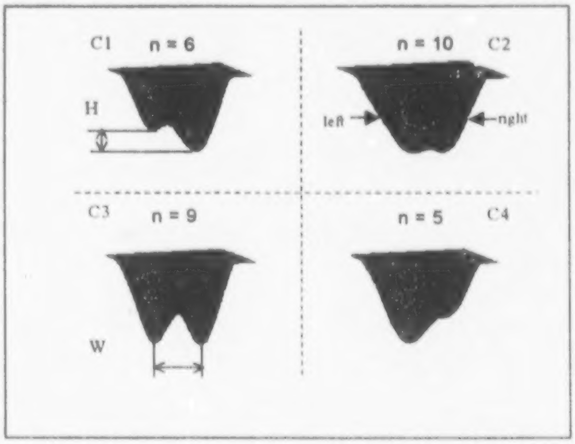


Figure 1. Dendrogram of the cluster analysis for 30 shapes. At a distance level of 0.2, four clusters can be distinguished.



	C1	C2	C3	C4
H (mm)	7.5± 3.3	0.4± 1.5	1.2± 2.7	- 7.7± 6.4
W(mm)	97.1± 9.1	71.2± 20.1	103.9± 18.3	80.8± 16.3

Figure 2. Mean shape for Clusters C1-C4

those in cluster C3. The five shapes in cluster C4 are distinct from the shapes in clusters C1, C2 and C3 with the left lobe lower than the right one.

DISCUSSION

Four clusters were identified by discriminating the variability in geometrical parameters of the elderly subjects' interface shapes and the mean shape of each cluster could be considered as a generic shape. In order to know whether the different generic shape patterns were caused by the different postures or not, our results were compared to those of Hobson (3), who found that on right trunk bending from the neutral posture, the left ischial tuberosity (IT) moved vertically upward about an average of 12.5±9 mm for the able-bodied subjects group and of 14±10 mm for the disabled. Unfortunately, the vertical differences between two ITs in neutral posture were not reported. Our results of the relative vertical position of the two lobes of mean shapes from subjects seated in neutral posture revealed that height differences were 7.5±3.3 mm for the mean shape of the cluster C1 and −7.7±6.4 mm for the mean shape of the cluster C4. Since in our study, care was taken to ensure that subjects were positioned in neutral posture, the obvious differences between mean shapes were probably not caused by posture but by intrinsic characteristics such as tissue tone and underlying skeletal structures. Subject with flaccid tissue exhibited a deeper, narrower contour than those with normal tissue (4). Thus, the cluster C3 of which the mean shape had distinguished lobes may contained more subjects with flaccid tissue than cluster C2 of which the mean shape had almost undistinguishable lobes. The effects of tissue tone and underlying skeletal structure on buttock-cushion interface shapes should be studied in the future as well as posture evaluation to confirm these observations. The results suggested that distinguishing of generic shape patterns may lead to a more comprehensive understanding of the seat interface shapes. Further analysis on different groups is necessary to deeply validate this method.

CONCLUSION

The cluster analysis grouped the seat interface shapes of 30 elderly subjects into four clusters. It appeared that the generic shapes were mainly characterized by the asymmetry of the shapes. The determination of elderly individual's interface shapes into four different functional clusters may lead to a better comparison with other wheelchair users' interface shapes than using a single mean shape. Furthermore, the generic shapes can potentially be used to develop several generic contoured seat cushions which could be less expensive than the custom contoured seat cushions.

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AN EVALUATION OF WHEELCHAIR SEATING SYSTEM CRASHWORTHINESS USING FEDERAL MOTOR VEHICLE SAFETY STANDARD (FMVSS) 207 TESTING

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ABSTRACT

Recognition of the importance of the vehicle seat in providing crash protection has increased significantly in recent years. Automotive seats require extensive testing to ensure compliance with government crashworthiness and occupant protection regulations. This study proposes to evaluate the crashworthiness of various Wheelchair Seating Systems (WCSS) using FMVSS 571.207 for Seating Systems [1]. The crashworthiness of three WCSS was tested by applying a forward and rearward load at the seating system's center of gravity (CGSS), and applying a moment to the upper most point of the seat back. The magnitude of the applied loads was established using FMVSS-207 guidelines. None of the tested WCSS or attached hardware showed significant permanent deformation or damage.

BACKGROUND

There has been an increase in recognition of the importance of vehicle seats in providing crash protection. Manufacturers of automotive seats are now required to perform extensive testing to ensure that their production vehicle complies with government crashworthiness and occupant protection regulations as described by FMVSS [2, 3]. Not only must the seat be secured so that it does not add to the loads on the occupant during a crash, but it must also be designed and constructed to provide support for the occupant under impact loading and during occupant rebound, thereby controlling occupant kinematics and optimizing the performance of occupant restraint systems. Despite an effort by an ANSI/RESNA standard (WC-19) [5] to evaluate wheelchair crashworthiness, the addition of often used after-market or optional wheelchair seating systems will invalidate testing and many wheelchairs with add-on seating systems will not be sled tested to evaluate their ability to withstand crash level forces [4]. The 'ANSI/RESNA Wheelchair Seating Used in Transportation' work group is designated to guide seating system design and address this issue through development of a standard. This study tests WCSS according to established FMVSS 571.207 requirements for seats, their attachment hardware and installation in order to minimize the possibility of failure during vehicle impact. The introduction of a wheelchair crashworthiness test attempts to establish safe wheelchair seating systems, which can be used in vehicles and improve crash safety for individuals using wheelchairs.

RESEARCH QUESTION

Do select, commercially available (adult manual recline, adult automatic recline, pediatric) seating systems and attachment hardware meet FMVSS 207 Seating System test requirements?

METHOD

The loads applied to the WCSS were generated using the Instron Series 4200 loading frame, which is designed to test materials in either tension or compression. The performance requirements of FMVSS state that the occupant seat (or in this case WCSS) shall withstand:

- 20 times the weight of the seat applied in a forward, longitudinal direction, at CGSS;
- 20 times the weight of the seat applied in a rearward, longitudinal direction, at CGSS;
- a force that produces a 3,300 inch-pound moment about a defined seating reference point, applied to the upper cross-member of the seat back, in a rearward, longitudinal direction;
- loads applied within 5 seconds, held for 5 seconds and reduced to zero within 5 seconds.

Seating System FMVSS 207 Testing

A rigid test fixture was developed to mount the three WCSS with attachment hardware onto the Instron 4200 loading frame. Additional test hardware was developed to make it possible for the load cell of the Instron 4200 to apply respectively a forward- or a rearward load at the CGSS, and a moment at the upper seat back cross member of the WCSS. The required force and cross head speed were programmed into the Instron 4200 computer, and the maximum extension and force were recorded by the Instron computer during each test. A linked HP-plotter also captured the maximum force applied to WCSS over time. All tests were recorded on video.

TEST SETUP

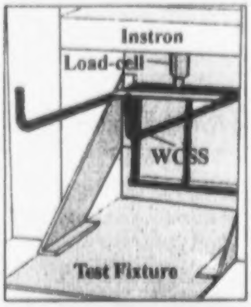
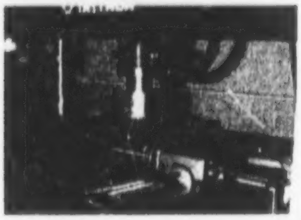
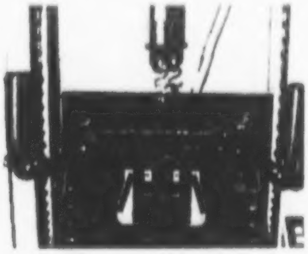
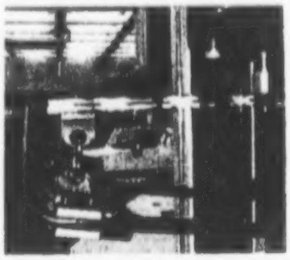


Figure 1a., shows the test fixture, test instrument and testing hardware for the ORBIT-pediatric seating system. Before running the test, the original seat back frame angle of the WCSS was measured using an inclinometer. To apply the directed loads and moments onto the WCSS, three different setups were needed to apply load to the WCSS (see Figures 1b, c and d).

Figure 1a: Instron 4200 Loading Frame with test fixture and WCSS







Figures 1b,c and d: Setup of WCSS and Instron to apply a forward load, rearward load, and moment respectively

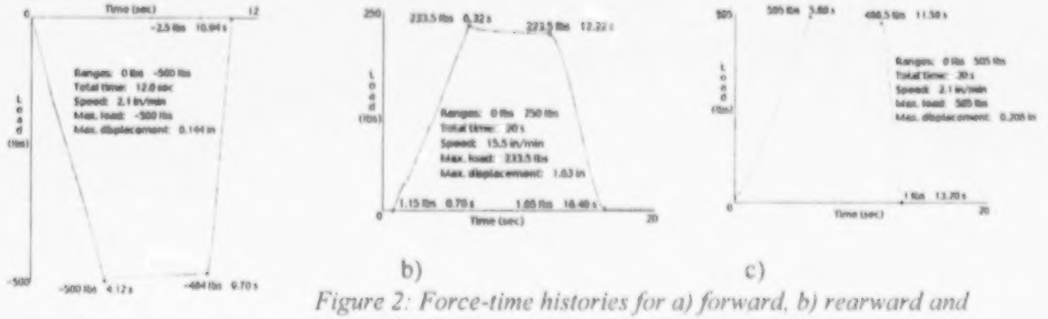
RESULTS

Before each WCSS was loaded, a small initial (5%) load was applied onto the WCSS in order to determine the rate of loading and the required cross-head speed. After the required load was applied to the WCSS, force-time histories were recorded as shown in Figures 2a, b and c. Table 1 shows peak seat back deflections, peak applied loads, moments and peak permanent seat back deflection of all three WCSS.

Table 1: Results of FMVSS 207 testing

		Forward Load			Rearward Load			Moment upper seat back			
Seating System	Weight (Lb.)	Peak Load. (Lb)	Peak Ext. (in.)	(deg)	Peak Load. (Lb)	Peak Ext. (in.)	(deg)	Mom./Dist (Lb.)	Peak Ext. (in.)	(deg°)	Permanent Seat Back Deflect. (deg)
Orbit	7.75	151	0.3	1.1°	170.5	0.4	2.7°	222.5	3.4	8.8°	0.1°
Taursas	24.5	500	0.1	0.9°	505	0.2	0.3°	233.5	1.6	2.0°	1.2°
LaBac	38.6	812	0.7	3.5°	772	0.6	1.5°	226	1.9	4.0°	1.0°

Table 1 shows that during both forward and rearward seat back loading, the LaBac had the largest peak deflections, which were 0.7 in. and 0.6 in., respectively.



a) b) c)

Figure 2: Force-time histories for a) forward, b) rearward and c) seat back moment tests of the Taursas Seating System

Although a higher load was applied to the Taursas than to the Orbit seating system due to their different weights, the former had the smallest peak deflections for both forward and rearward load testing. Among the three WCSS, the Orbit seat back showed the largest deflection during the moment test. The Taursas and the LaBac had permanent deflection of respectively 1.2° and 1.0°. Compared to these two seating systems, the Orbit seating system showed a very small permanent deflection of 0.1°. Permanent deflection of the Taursas and the LaBac seating systems show that these seating systems absorbed some energy due to the applied forces and moments on the seat backs.

CONCLUSIONS

The FMVSS laboratory procedure was used to evaluate crashworthiness of three WCSS. WCSS tested in this study met FMVSS 207 test criteria and withstood loads without large elastic or permanent deformations. Greater loads applied to the heavier WCSS, resulted in a larger permanent deflection of the seat back. Additional WCSS and attachment hardware as well as seat surfaces will be evaluated in future efforts. This low cost static load test does not imply a crash-proof WCSS, but is a first step towards evaluating WCSS and attachment hardware for safe use on wheelchairs used as motor vehicle seats.

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COMPUTER MODEL FOR THE DESIGN OF WHEELCHAIR CUSHIONS

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ABSTRACT

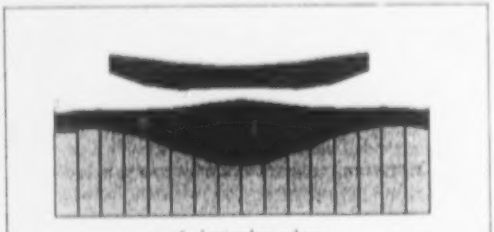
A computer model based on the finite element method was developed to study pressure distribution at the buttock-cushion interface. By means of loading simulations on wheelchair cushion models, this computer-aided system is able to provide comparative information for a variety of concepts and refinements of seat cushions. The load applicator consists of a finite element model of a rigid buttock, the geometry of which is based on data obtained from the CASS (2). A multilinear model of the nonlinear stress-strain curve(s) based on experimental results controls the mechanical behavior of the cushions. Models of a contoured and flat seat cushion have been tested.

BACKGOUND AND OBJECTIVES

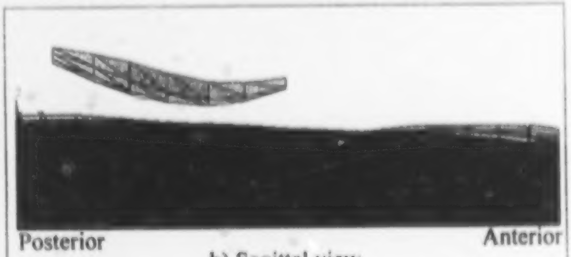
The prolonged seated position often leads to pressure problems, mainly because a relatively small area supports a great part of the user's weight. In fact, one of the major cause of pressure sores is the application of forces to the skin surface for prolonged periods of time (1). It is recognized that the reduction of peak pressures is critical in protection from tissue trauma (4). Up to now, there are still no universal and precise guidelines for the design of cushion geometry and its related mechanical properties. According to Lim et al. (5) the most critical extrinsic factors are the features of supporting seating surfaces with respect to pressure distribution. Unfortunately, the relation between the seating material and shape with the human buttock during contact is not well documented, and only few studies have been reported so far. Brienza et al. (2) studied the relationships between support surface shape, interface pressure and soft tissue distortion using a computer-aided seating system (CASS). Todd and Thacker (8) developed a finite element model to study the stress distribution throughout the soft tissues between the cushion and the ischial tuberosities. Other studies have also presented physical models of the buttock under load (7). The specific objective of this paper is to present a new tool based on finite element modelling which is able to simulate the stress distribution as well as the mechanical behavior of seat cushions under static loads applied by buttock models. This mechanical tool should be useful to compare, by means of simulations, different concepts of cushion designs.

METHOD

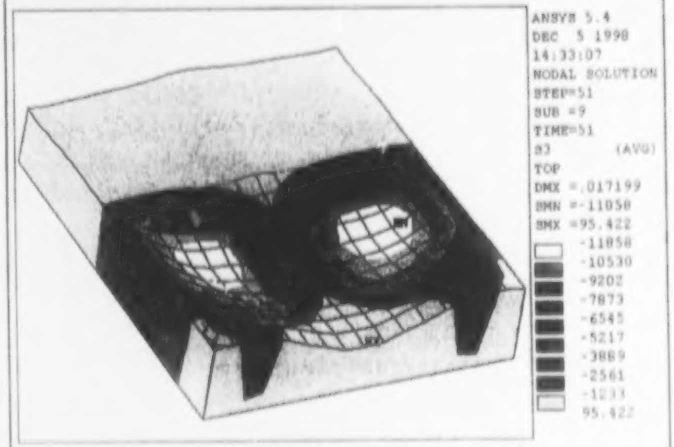
The computer model was developed using the ANSYS software (Mechanical Dynamics inc.) to study pressure distribution at the buttock-cushion interface. It consists of a finite element model of a cushion and a rigid buttock. The cushion model was meshed using 288 20-node solid elements. The hyperelastic mechanical properties of different foams were obtained from resulting curves obtained from Indentation Force Deflection tests following the ASTM 3574-95 standard. Preliminary validation of the cushion model was reported previously and showed a maximal error of 5 % for the force-deflection curves (3). The buttock model was built with 84 4-node shell elements. Its geometry is based on the optimal shape of deformed buttocks in a seating position obtained using the CASS (2). In fact, it corresponds to a symmetrical buttock model based on the mean buttock shape of 30 elderly subjects. The buttock model is completely rigid and acts as a load applicator. A computer program was developed to simulate loading from the buttock to the cushion in accordance to nonlinearities and large strains in the cushion material. About 500 point-to-surface contact elements were used to model the buttock-cushion interface and to take into account the stiffness and damping of the cushion and buttock during contact. Preliminary tests were carried out on two different seat cushion geometries made of a polyurethane soft foam (Multifoam International Inc.) with external dimension of 16 " x 18 " (406 mm x 457 mm). The first one was a standard rectangular cushion of 3 " thickness (76 mm), while the second one, shown on figure 1a) and 1b), was a contoured shape cushion measured using a 3D digitizer (Microscribe 3D, Immersion Corp.). The two cushions were modelled using one layer of elements. The mechanical properties of both cushions were defined using a nonlinear stress-strain curve that takes into account the hyperelastic properties of the foam (3). All degrees of freedom of the nodes located on the bottom plane of the cushions were constrained to account for the rigid support surface. The load applied by the buttock model on the cushion models was about 65 % of the weight of a 79 kg person (50th percentile), which approximates the weight supported by the buttock area (516N). The normal stress (minimum principal stress), which is analogous to the pressures often measured clinically (8), as well as the deflection (vertical axis) at the cushion surface were extracted from the simulations.



a) Anterior view



b) Sagittal view



c) Stress results

Figure 1 : a) and b) Finite element models of the buttock and contoured shape cushion (anterior and sagittal views) and c) stress results after loading simulation.

RESULTS

Figure 1c) shows stress results for the contoured seat cushion. Results showed differences between both cushions. A 16 % difference was observed for the maximal values of the normal stresses indicating larger pressure for the flat cushion. Another 49 % difference was found in the values of maximal deflections along the vertical axis indicating larger deformation also in the flat cushion. Concerning the uniformity of the stress distribution, the contoured cushion showed a 11 % lower standard deviation of stress results.

DISCUSSION

Preliminary simulations showed the feasibility of the finite element approach to simulate the nonlinear interaction between the buttock and the cushion. The normal stress distribution is in agreement with previous studies

(3,6), which stated that the computer model is able to represent the nonlinear behavior of foam materials. As generally observed in clinical situations, the results showed lower maximum stresses for the contoured seat cushion than for the flat seat cushion. The simulations show differences in the load distribution of the two cushions as well as in vertical deflections and demonstrate the potential of the finite element model to objectively compare and evaluate seating devices. This finite element model may also help to provide additional information concerning cushion selection.

Further validations and improvements of the model are in progress. Current work is focusing on modelling other types of cushion in order to explore new concepts of seating devices and compare them to actual designs. A protocol, including a design process, is also part of future work that tends to define the procedures and the proper shape and materials to be used for the design of more appropriate seating devices using computer simulations.

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A CASE REPORT FROM CLINICAL EVALUATIONS OF THE PROTOTYPE BODY MAP CUSHION

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ABSTRACT

A novel suspension-type wheelchair cushion has been developed that can improve wheelchair cushion performance by shifting pressure away from the ischial tuberosities, sacrum and coccyx while providing stability and support for the user. The use of neoprene layers and optional cutouts also allows for adjustment to accommodate pelvic deformities. Clinical evaluation results for one client with spinal cord injury are presented in this abstract. Additional clinical evaluations are ongoing and will provide information about the cushion's design and performance.

BACKGROUND

An effective cushion reduces pressure over bony prominences while providing stability and support, primarily through envelopment. The main types of wheelchair cushions can be described as fluid, compressive (elastic, viscoelastic), or suspension cushions. Fluid and fluid-like seat cushions achieve envelopment by accommodation of bony prominences and maintain the condition by virtue of their ability to dynamically adjust to changing loading conditions. However, the dynamic nature of fluid-filled cushions often leads to the undesirable characteristic of poor stability.

Cushions made from elastic materials such as high resilient foams must rely on pre-contouring to achieve envelopment. Such a cushion has no ability to dynamically adjust beyond the limits of the compliance of the material as defined by its material properties. That is, these cushions cannot change shape without a tendency to return to their original shape. When a person sits on the cushion both the cushion and buttocks will deform until force equilibrium is reached. In the cushion, the counter forces will be greatest where there is the most deformation and least where there is low deformation. Enhanced stability is provided due to the foams tendency to hold its shape and, thus, hold the person in place. A fluid like cushion would instead change its shape to accommodate changing load. The disadvantage of pre-contoured compared to fluid like strategies is that the distribution of forces are sensitive to the relative match between the cushion and buttock shapes, and to the positioning of the buttocks on the surface. Cushions made from viscoelastic materials have a combination of elastic and fluid properties giving such cushions some ability to reconfigure in a memoryless fashion and some ability to provide stability through resilience. However, an optimum balance of viscous and elastic response is a matter a personal preference and need, and varies significantly from person to person.

Suspension cushions use the strategy of removal of material in the areas that commonly experience high pressure and use covers under tension to support these areas in a suspension-like manor. Suspension cushions remove material from the ischial and often the sacral area, as well. A new suspension cushion—Body Map Cushion—is under development and recently went through a multi-site clinical evaluation. Unlike other suspension cushions, the Body Map uses a neoprene membrane and foam contours to provide support under the pubic arch. This paper presents further description of the cushion and results for one subject that participated in the evaluation.

OBJECTIVE

To evaluate the efficacy of the Body Map prototype cushion for an individual wheelchair user with a need for accommodation of pelvic deformity and pressure reduction.

APPROACH

The subject, JC, has a level C5-6 incomplete spinal cord injury. He does not have a history of pressure ulcers, but has factors that increase his risk. JC has a moderate, fixed posterior pelvic tilt and approximately a 0.5 inch flexible, right obliquity. Upon presentation, he used an E&J Vision Barracuda with a Stimulite Classic cushion. The evaluation protocol consisted of an Initial Evaluation that included the collection of background information, pressure measurements, functional tests, subjective feedback, a clinical assessment, and the fitting of a BodyMap seat cushion. Pressure measurements were taken with an FSA pressure-mapping device (FSA Pad, Vista Medical, Manitoba, Canada) on the subject's cushion, flat foam on a plywood base, and the final fitted BodyMap cushion. A one-week Follow-up Phone Call included the same subjective feedback and several additional questions. A one month Follow-up Evaluation included a repeat of the functional tests, subjective feedback, and pressure measurements on the BodyMap cushion.

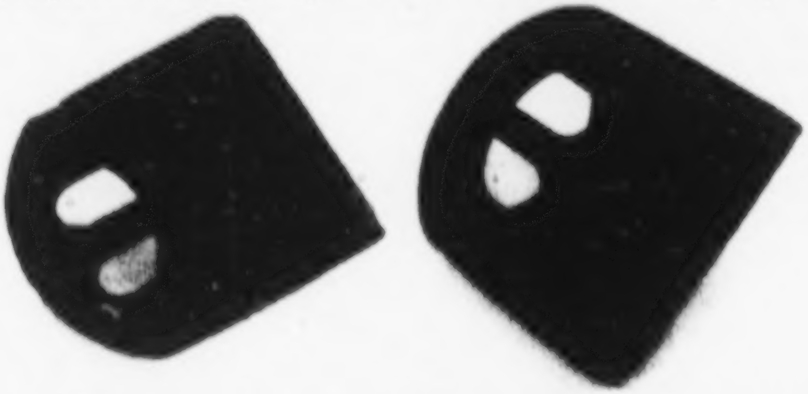

Fig 1 – Body Map Cushion foam support (top shown on the right, bottom shown on the left)

The cushion consists of up to 5 components: the foam support structure (basic cushion), the high support suspension liner, the adaptive suspension liner, cushion cover, and cushion spacers (1/2 and 1 inch). The foam support structure (pictured in Fig 1) is constructed from four types of foam varying in firmness and shape, and an internal membrane of neoprene rubber. The foam support is glued together and bonded to a rigid stiffener plate on the bottom, then covered with a waterproof coating. The foam support has two oval cutout areas under the ischial tuberosities to provide pressure reduction. The outer rim of the foam support is rigid and designed to support the various tension layers that suspend the person seated on the cushion. Assembly and fitting of the cushion involves the removal or addition of the liners, spacers, and covers. The spacers can be added beneath the foam support structure to increase overall thickness from 3 to 3.5 or 4 inches and hence accommodate greater protrusion of bony prominences into the cushion. The foam support structure and spacers fit inside the high support suspension liner. This liner has perforated, water resistant neoprene rubber on top, and bottom and sides made of a durable, water-resistant material. It acts as the primary suspension membrane to provide the Body Map with its unique pressure-reduction capabilities. The adaptive suspension liner can be added under the high support suspension liner to allow for additional support and pressure or postural adjustment. The adaptive suspension liner also contains a neoprene rubber layer, which can be cut out on the right or left side to accommodate a pelvic obliquity. The cushion can then be covered in a Polartec, Lycra, or Darlexx cover. The components work together to form a cushion system that can be tailored to the clients needs.

RESULTS

Fitting JC with the Body Map cushion took approximately 20 minutes. The final configuration consisted of the foam support structure with an adjustable suspension liner with a left ischial cutout, the high support suspension liner, and a Lycra cover. This configuration was chosen because it corrected for JC's flexible obliquity and provided him with good pressure readings and comfort. JC's overall sitting height was increased by approximately 1.5 inches.

Three pressure mat readings were taken and the results averaged for the top 10 values in each frame. The average pressures for the Stimulite, flat foam, and Body Map cushion were 106, 89 and 91 mmHg, respectively. The Body Map effectively shifted pressure off the ischial tuberosities to the periphery of the ischial area and reduced peak sitting pressures. JC immediately felt that he was sitting more level on the Body Map and that it reduced his back discomfort. During the follow-up interview and evaluation, he also indicated that he was feeling less back discomfort with the BodyMap and was sitting more upright. He noted that he was able to sit longer on the BodyMap. He got used to sitting higher on the BodyMap, but had to adjust his transfer between his wheelchair and van seat. He feels the increased comfort far outweighs the changes he had to make to accommodate the increased height. JC will continue to use the BodyMap as his primary cushion. He rated it 5 out of 5 for Overall Satisfaction.

DISCUSSION

The major benefits to JC of the Body Map cushion appeared to be the ability to easily accommodate pelvic deformity, the stability provided by the immersion and envelopment properties of the cushion, and the low maintenance. From the clinicians perspective, the adaptations were easy to accomplish. In general, there appears to be enough immersion and tension in the front of the pocket to act as an ischial block for those patients with posterior pelvic tilt (e.g., many elderly) and prevent sliding forward. There are options for increasing the degree of immersion by varying the layers of fabric. To some extent, the cushion allows accommodation for pelvic rotation or other bony prominences through cutting out of the liner, without loss of favorable pressure distribution. The provided stability without loss of immersion is important. Stability improves one's ability to transfer, weight shift in the chair (side to side) and perform functional tasks in the chair. Additional clinical evaluations are currently ongoing to collect pressure data and feedback from a larger sample of potential users. The results will be used to further refine the cushion design and evaluate its performance.

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DESIGN OF A UNIVERSAL CANOE SEATING SYSTEM

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ABSTRACT

Access to water-based outdoor recreation such as canoeing is difficult for individuals who have impaired sitting balance. Bench-style canoe seats do not provide paddlers with adequate support for the pelvis and trunk. Existing cushions and backrests for canoe seats do not meet the needs of individuals who do not have independent sitting balance. The purpose of this project was to design a concept prototype for a modular universal canoe seating system to provide adequate support for a variety of users. The prototype was designed to improve pelvic stability, trunk support and comfort for all paddlers. It was designed to be suitable for use with commercial canoes used by rental, outfitting and instructional programs. The system is adjustable and modular to accommodate a wide range of individuals. It includes a basic seating system with pelvis and low back support suitable for all users, and extended support(s) for users without independent sitting skills.

BACKGROUND

Canoeing enhances access to outdoor and wilderness environments by providing transportation to areas that cannot be reached by land, or are inaccessible for people with mobility limitations. This group may include older adults, families with young children, and people with disabilities. Thirteen million canoes are rented or used in outfitting or instructional programs each year (1). Canoe rental facilities and instructional programs currently rely on commercially available seats. The paddler using these seats must use balance and leg strength to maintain an effective sitting position.

STATEMENT OF THE PROBLEM

Standard canoe seats provide a bench for the paddler to sit on or lean against. They do not stabilize the pelvis or provide lower back support. The functional benefits of pelvic stability are well documented for wheelchair users (2, 3). Just as a wheelchair user needs a stable pelvis to optimize function, the canoe user must maintain similar levels of stability to effectively paddle. Paddlers with no physical impairment can use leg, hip and trunk muscles to stabilize the pelvis and trunk. Although commercially available backrests are available, they are not designed to support individuals who are unable to sit independently. Such individuals must rely on an external back support system. Commercial canoe backrests do not provide lateral support for pelvic stability and have a minimal and often unstable attachment to the existing seat. In addition, commercially available seats usually do not provide padding sufficient to prevent pressure ulcers or abrasions, and are usually not compatible with the use of a personal cushion or seating system.

Although a variety of canoe seats have been developed for use by specific individuals, none of the canoe seats specifically designed for people with disabilities are commercially manufactured. Improvised or temporary supports, such as canoe packs or bolsters, do not provide adequate support and may shift with the movement of the canoe. Sitting in the bottom of the canoe offers greater stability but does not allow the user to paddle effectively.

DESIGN

This project involved the design of a concept prototype for a modular canoe seating system capable of providing improved pelvic and low back support, stability and comfort for users with and without disabilities. The concept system is modular to provide different amounts and locations of support. It consists of a seating frame, adjustable pelvic supports, backrest extension with adjustable backrest upholstery, lateral trunk supports, and attachment hardware. The system was constructed of materials similar to those used in current lightweight wheelchair construction.

Basic Seating Module

The basic seat module consists of a base plate, adjustable hip supports, aluminum tubing, clamp bars and assorted fasteners (Figure 1). The adjustable pelvic supports provide posterior and lateral pelvic stability and support. The pelvic supports are molded thermoplastic and are padded. The supports are adjustable in width. The seat-to-back angle is adjustable to maximize comfort and function.

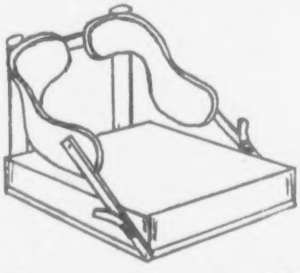

Figure 1. Basic Seat Module

Backrest Extension

Additional trunk support can be added to the base unit by adding a backrest extension (Figure 2). The backrest extension is fitted with adjustable tension upholstery.

Lateral Trunk Supports

Add-on, lateral trunk supports provide additional upper trunk support to paddlers with limited sitting balance (Figure 2). Commercially available lateral trunk supports are suitable for this purpose.

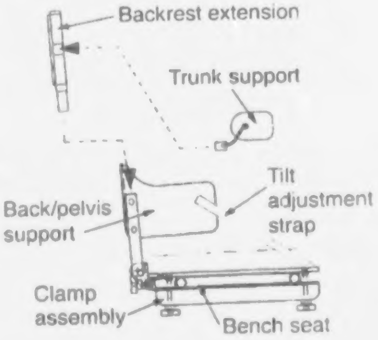

Figure 2. Prototype Canoe Seat

Attachment Hardware

The seating system attaches to the existing bench-style canoe seats found in most rental canoes. The lower portion of the attachment system consists of two sections of polyethylene bar stock. These bars clamp to the existing canoe seat using turn-knobs and stainless steel studs which protrude from the bottom of the seat frame (Figure 2).

In the interest of safety, the seat system does not utilize straps or other components that physically attach the paddler to the canoe or hinder egress.

DEVELOPMENT

The concept of the Universal Canoe Seating System originated from years of clinical experience in wheelchair and adaptive sports seating experience and dissatisfaction with commercially available canoe seats. A variety of commercially available canoe seats were tried, but good pelvic and trunk support was not provided by existing commercially available products.

The proof of concept device was fabricated and mounted on the fore and aft bench seats in two different canoes commonly used by canoe rental outfitters.

EVALUATION

The prototype system was evaluated on land by three seating experts and three others to obtain subjective feedback on the comfort and support provided. In addition, the device was tested on a river by two experienced paddlers with spinal cord injuries. The evaluators reported perceived benefits of increased comfort, increased pelvic support, increased low back support, greater seat cushion comfort, better stability when leaning, and increased paddling efficiency. Areas identified as needing additional development include an adjustment for height of the back support, a method of leg stabilization, easy adjustment of lateral pelvic supports and a slightly shorter seat depth.

DISCUSSION

The initial feedback from evaluators indicates that the prototype canoe seat is effective in providing improvements to pelvic and trunk stability and increasing comfort. More research is needed to incorporate suggested improvements and features. Areas that will require further development include the strength and durability of the materials used to fabricate the device and safety for the system user.

Several evaluators requested additional hardware to stabilize the lower extremities. Development of this hardware could significantly improve lower extremity and pelvic stability but will also create additional problems for ingress and egress.

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WHY WHEELCHAIR CONSUMERS USE THEIR POWERED TILT/RECLINE SYSTEM

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ABSTRACT

This paper presents the reasons for which 40 adults wheelchair consumers use their powered tilt and/or recline system. A short questionnaire was developed and used for interviewing the subjects at home. They were asked to select from a list of 25 objectives, the reasons for which they used their repositioning system and to rank them in order of importance. For each objective, they were also asked to identify the frequency of use, the range of tilt/recline and their degree of satisfaction. Results revealed that the majority of subjects use their repositioning system for comfort and rest and that only a minority of subjects uses them for physiological or postural reasons. Future outcomes research should investigate the effect these repositioning systems have on the wheelchair user.

BACKGROUND

When seated in their wheelchair, many elderly and severely disabled individuals are unable to change their position in order to regain their comfort. As a result, prolonged sitting without change in posture can lead to discomfort, pressure sores, decreased range of motion, spinal curvatures, cardiovascular and respiratory problems, decreased urinary and gastrointestinal function, behavioral changes and loss of functional independence (1,2,3,4). In order to counter the harmful effect of the prolonged static sitting position, adjustable tilt and/or recline systems are commonly used. While clinical studies emphasize the many objectives and the contra-indications of using those repositioning systems (5,6,7), most scientific studies to date tend to focus on pressure distribution (8). But yet the reasons for which the wheelchair consumer in fact uses this type of equipment are largely unknown. The purpose of this study was therefore to identify the reasons for which powered wheelchair consumers use their tilt and/or recline systems.

RESEARCH QUESTION

For what reasons are powered tilt and recline systems used by wheelchair users living at home?

METHOD

Sample

Forty adults who owned a powered wheelchair with a powered tilt and/or recline system were recruited from two Montreal rehabilitation facilities. The sample consisted of 8 women and 32 men with a mean age of 46 years (range 21-69); all subjects lived at home. Seventeen subjects had multiple sclerosis, six had muscular dystrophy, six were spinal cord injured quadriplegics and the remaining 11 subjects had a diagnosis of another type. Ten subjects had a powered recline system, 26 a powered tilt system and 4 subjects had both systems. They were all living at home and had their power wheelchair and seating devices paid by the provincial health insurance program.

Procedures

A literature review and two focus groups (implying users and clinicians) were conducted to identify 25 objectives of use of tilt and recline systems. A short questionnaire was developed thereafter to identify the reasons for which wheelchair users living at home use their powered tilt and recline systems. The questionnaire consisted basically of a list of 25 objectives that represented five categories of reasons for using a powered repositioning system: (1) comfort, (2) rest and relaxation, (3) posture, (4) functional independence and (5) physiological functions. For each objective, the subjects were asked to identify the frequency of use (using a 5-point scale); the range of tilt or recline (using a 3-point scale) and their degree of satisfaction (using a 5-point scale). From the list of 25 objectives, the subjects were then asked to select the 8 most important reasons for using their repositioning system and to rank them in order of importance. The subjects were thereupon invited to comment on how their tilt and recline system could be improved. The questionnaire also included general demographic questions as well as questions related to the problem of sliding in the wheelchair. The evaluations were conducted at the subjects' place of residence and were administered by the same occupational therapy student.

RESULTS

Results showed that all subjects used their powered tilt and/or recline systems and that 95% of them use it several times each day. With regard to satisfaction level, a rate of 5 (very satisfied) was attributed in 93% of the situations of use. Figure 1 illustrates the percentage of subjects who use their powered repositioning system for each of the 25 reasons listed. The results showed that 70% or more of the subjects use their repositioning system to increase their comfort, to rest (i.e. snooze, lie back), to decrease their discomfort, to relax (i.e. while listening to music or TV) and to decrease or alleviate pain. At the opposite end of the spectrum, only 33% of the subjects or less use their tilt and/or recline systems to facilitate wheelchair propulsion, to prevent skin redness, to help breathing, to prevent pressure sores, to avoid sliding in the seat, to make dressing easy and to facilitate bowel function. The figure also shows that between 41% and 56% of the subjects use their repositioning system for functional activities such as transfers, going up and down a sidewalk or an incline, feeding, personal hygiene and approaching objects.

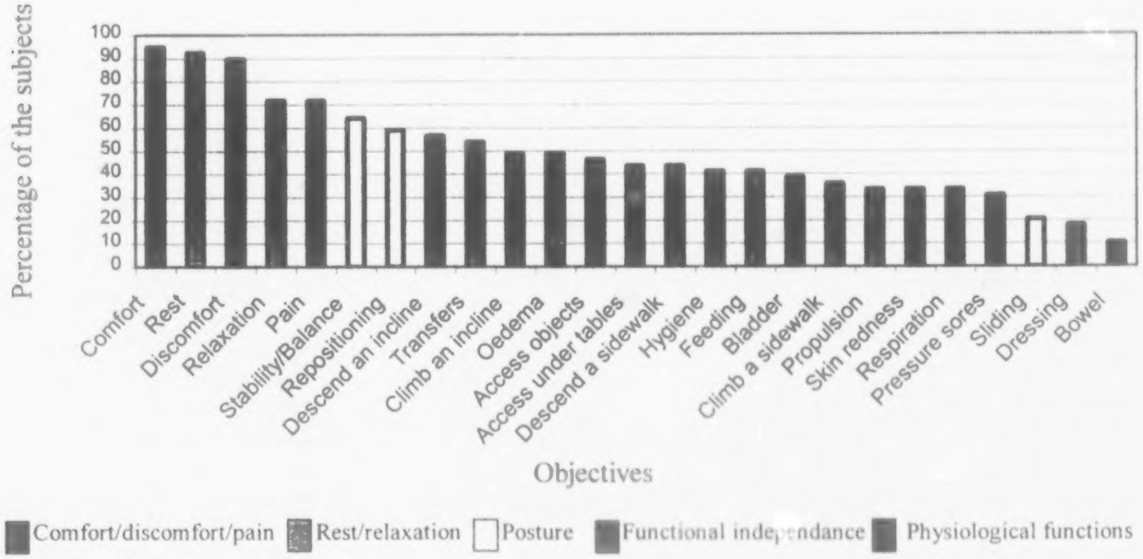

Figure 1. Percentage of the subjects who use their repositioning system for each objective of use

DISCUSSION

The results of this study yield information about consumers' views in a way that extends our understanding of how powered repositioning systems are currently being used at home. Overall, the subjects in this study used their tilt and/or recline systems several times daily and were very satisfied. More than 70% of the subjects reported that they used their repositioning system to improve their comfort, to rest and to be functionally independent. They felt that their needs in terms of comfort, rest and functional independence were more important than the physiological and postural reasons for which these tilt and/or recline systems are generally prescribed in order to be covered by the Quebec provincial health insurance program. These results confirm clinical opinion that powered tilt and/or recline systems should be prescribed and funded for reasons other than purely medical. In addition to outcomes data on consumer use of repositioning systems, future studies should address the effect of repositioning on user comfort, satisfaction, functional independence and various biomechanical parameters. It is this kind of outcomes research that will likely have an impact on the conditions and criteria used to fund these devices as well as on the quality of life of wheelchair users who could benefit from this type of assistive technology.

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A NEW QUANTITATIVE METHOD TO ASSESS DYNAMIC STABILITY OF SEAT CUSHION DURING SEATED REACHING TASKS

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ABSTRACT

This study presents a new quantitative method to assess dynamic stability of seat cushion during seated reaching tasks. The relationship between the velocity and the maximal distance covered by the center of pressure (COP), at the body-seat interface, provides insight into dynamic stability. A seat cushion is said to be stable when it allows the COP to cover a longer distance fastly during voluntary reaching tasks.

BACKGROUND

The sitting position is basically unstable without additional external support. This is because the hip joints are in an intermediate position and the trunk cannot be locked relative to the thighs by ligamentous restraint. As a result, muscle activity is necessary for fixation of the trunk when sitting without additional stabilizers [9]. Sitting balance is not a functional activity, but the ability to maintain or attain sitting balance is believed to be necessary to perform functional activities such as dressing, transferring, and eating [1-3,6]. However, the manner in which the body is stabilized while performing reaching tasks is not well understood [7]. In the past, comparing observational data of balance during leaning and reaching sideways with quantitative data from force platform has revealed a weak relationship [3,4]. In the other hand, experimental studies have shown that adding external stabilizers such as a chest belt or a training program, have a positive effect in increasing functional reach and so sitting stability [1,2]. In terms of body movement, it was found that reaching longer and faster represents a gain in sitting stability. This was confirmed on a recent study reporting COP displacement. In fact, Seelen et al. [6] found that antero-posterior COP displacement was larger and faster for able-bodied subjects during bi-manual forward reaching when compared to the spinal-cord injured group. In the previous studies, the effect of seat cushion on sitting balance has not been examined from a quantitative viewpoint. Furthermore, it is well known that the stability of cushion is considered to be the most important characteristic of sitting support after pressure distribution [8]. A cushion with a minimum level of stability is not only perceived as being uncomfortable, but it can also have negative effects on the sitting posture such as increased internal work [9]. Recently, Pai & Patton [5] examined the interplay between velocity and position of the body center of mass in balance dynamics. They found that the traditional view according to which horizontal center of mass positions must reside inside the base of support to guarantee maintenance of balance does not sufficiently define the feasible region for movement termination. We apply here this theory to the COP at the level of seat interface to examine the relationship between the velocity and the distance covered by COP during standardized reaching tasks. In this study we hypothesized that sitting balance is influenced by seat cushion when performing reaching movement tasks, and that seat cushion is considered stable when it allows the center of pressure to move faster and covered a larger distance.

METHOD

Seven stroke subjects were recruited from the Rehabilitation Institute of Montreal. Subjects had a diagnosis of stroke resulting in lateral hemiplegia at least 6 months ago. No subject had hemianopsia or any obvious cognitive or perceptual problems. The mean age, weight and height were respectively equal to 57 ±9 years, 71.7 ±11.9 kg and 1.68 ±0.09 m for the disabled group. Subjects were asked to sit on a height adjustable stool. Seat height was adjusted to 100% lower leg length. The distance between right and left ankle joint was fixed to 15 cm. The distance between the popliteal fossea and the front edge of the seat was fixed to 4 cm. Subjects started with the unaffected hand resting on pressure-sensitive switch button (I) that was placed on the side of the stool. An alarm signaled the start of hand movement. The subject reached a second switch button (II) at natural speed in two directions, 45° ipsilateral and 45° contralateral from the sagittal plane. Reaching distance was standardized to 130% of arm length, while the height of the switch button (II) was standardized to 100% of the gleno-humeral joint height as measured from the floor in the urpright seated posture. The subject maintained the switch button (II) pressed for at least two seconds and then returned to press the switch button (I), which ended the trial. Subjects performed three trials for each condition (sound and paretic hand), and with three seat cushions (Roho, flat-foam (F-foam), and contoured foam (C-foam)). During reaching tasks, pressure distribution at the body-seat interface was recorded at 50 Hz using a FSA mat (VistaMedical, Inc.). The trajectory of the center of pressure (COP) was computed for each sample from the pressure distribution data. A median low-pass filter was used to filter displacement data of COP. A numerical central differenciation method was used to estimate the instantaneous velocity of COP. The maximal covered distance (MCD) as well as the maximal velocity (MV) of COP were calculated. A paired T-test was used to compare the effect of different cushions on MCD and MV parameters.

RESULTS & DISCUSSION

Figure 1 shows a typical diagram representing the variation of the instantaneous velocity of COP with respect to the cumulative distance covered by COP for one hemiplegic subject using his paretic hand in the ipsilateral direction during reaching task. In general the center of pressure reaches a maximum velocity at mid-distance of a reaching target. This is due to the acceleration and deceleration process of total body center of mass.

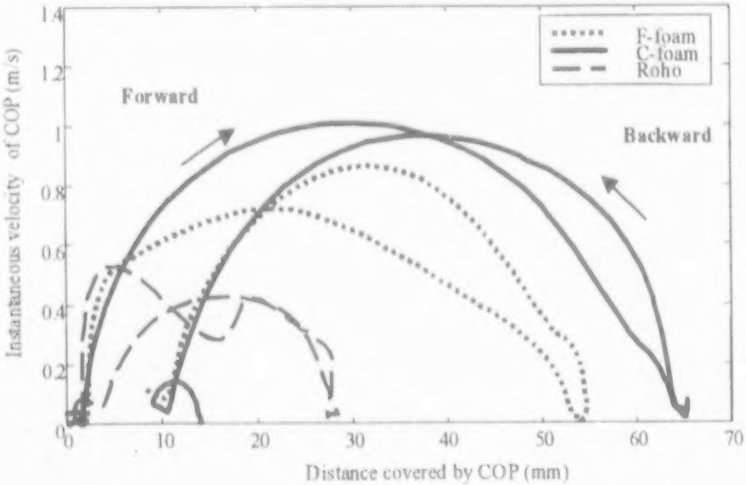

Figure 1: Velocity-position COP relationship during reaching task for one hemiplegic subject using his paretic hand in the ipsilateral direction.

We noticed also that the forward velocity of COP is almost always greater than the backward velocity. In fig. 1, the COP covers a distance of 65 mm and reaches a speed of 1 m/s when the contoured foam (C-foam) cushion is used. This represents twice the COP distance and velocity for the Roho cushion. This trend is generally present for all subjects (Table 1). The results shows that C-foam is more stable than Roho since the former allows the COP to cover larger distance at higher speed, which is in agreement with Seelen et.al [6]. It is not surprising that when using the paretic hand in the ipsilateral direction, the subjects were able to move their COP longer with a higher speed since it is the sound part that controls the movement during this task. However, due to large variability between subjects, only two cases are statistically significant. This variability could be partially explained by varying patterns in the foot support reaction forces, although the subjects were instructed to reach the target the same way for each cushion. Clearly, this method shows a new quantitative way to assess dynamic stability of cushion. However, care must be taken when interpreting data for spinal-cord injured people since our subjects were able to walk short distances within the home, and had the ability to sit unsupported.

Table 1: Mean and (SD) of maximal covered distance (MCD) and maximal velocity (MV) of COP during reaching tasks for three type of cushions ROHO, contoured foam C-FOAM, and flat foam F-FOAM. (*) significant difference (p=0.02) between ROHO and C-FOAM. (†) significant difference (p=0.01) between C-FOAM and F-FOAM. (N=7)

		SOUND HAND		PARETIC HAND	
		IPSILATERAL	CONTRALATERAL	IPSILATERAL	CONTRALATERAL
ROHO	MCD (mm)	55.8 (18.1)	33.9 (9.5)	72.9 (26.5)	49.1 (22.5)
	MV (m/s)	1.24 (0.48)	0.72 (0.26)	1.39 (0.58)	0.93 (0.37)
C-FOAM	MCD (mm)	70.8 (27.9) *	38.1 (8.6)	81.6 (31.2)	57.1 (29.3)
	MV (m/s)	1.29 (0.55)	0.72 (0.34)	1.68 (0.69) †	1.12 (0.55)
F-FOAM	MCD (mm)	58.0 (16.7)	35.7 (11.1)	71.6 (23.5)	53.6 (26.9)
	MV (m/s)	1.18 (0.39)	0.76 (0.30)	1.34 (0.51)	1.05 (0.53)

CONCLUSION

In this paper, we demonstrate that it is feasable to assess dynamic stability of cushion using pressure distribution measurements when reaching or leaning sideways. The velocity-position COP relationship provides insight into dynamic stability of seat interface. It appears that the contoured foam used in this study is more stable than the flat foam and the Roho type cushion.

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EFFECT OF DIFFERENT TILT AND SEAT-TO-BACK ANGLES ON TRUNK, PELVIC AND HIP ORIENTATIONS

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ABSTRACT

For many disabled persons, an adequate sitting posture is essential to maintain skin integrity. Studies have shown that variations in sitting positions may reduce the prevalence of pressure sores. However, little is known on the effects of these sitting variations on posture. The aim of this study was to evaluate the orientation of the trunk, pelvis and hip, for 12 spinal cord-injured people in 8 sitting positions, by means of external markers placed on anatomical landmarks and reconstructed in 3D with a Motion Analysis System. Preliminary results show that the trunk, pelvis and hip angles are related to the backrest angle; that the pelvis and hip angles are influenced by the system tilt, and that posture is not significantly modified when back and forth sitting changes are done.

BACKGROUND

For spinal cord-injured (SCI) people who are not able to reposition themselves, prolonged periods of sitting may cause problems, such as skeletal deformities and pressure sores, even if care was taken during the positioning. Studies (2, 3) have shown that variations of tilt or seat-to-back angles, and forward or lateral leanings, modify the pressure distribution at the seat interface, which may reduce the development of pressure sores. But these sitting changes may influence the sitting posture. Nwaobi (6) studied the relationship between different seat-to-back angles and hip flexion with children (normal, cerebral palsied). This study revealed that the seat-to-back and hip angles are not equal, but that the difference between the two decreases as the inclination of the backrest increases. The author concludes that the hip angle should not be described as the seat-to-back angle. Gilsdorf (1) showed that, for noninjured people, an increase in the seat-to-back angle followed by the return to the upright position, causes an increase in both normal and shear forces. These results may indicate postural changes, which were, unfortunately, not measured in this study. Studies conducted by Hobson (3) and Koo (4) showed that lateral and forward bendings result in non-equivalent postural changes; the posture was also not computed when returned to the neutral position. From these studies, it is clear that the posture is influenced by forward and lateral inclinations, and the backrest angle. But the influence on postural alignment of different seat tilts or returns to the first position, is yet to be studied.

RESEARCH QUESTIONS

The objective of this study was to characterize the trunk, pelvic and hip orientations by means of external markers reconstructed in 3D, in relation with different tilt and seat-to-back angles for a SCI group of people. The hypothesis are that 1- modifications in the wheelchair sitting orientation influences the trunk, pelvic, and hip angles, and that 2- the return to a neutral position, after different sitting changes, does significantly modify the initial posture.

METHOD

Twelve SCI subjects (3 females, 9 males) participated in the study. Except for one subject who had quadriparesis, all subjects were quadriplegics. The group had a mean age of 38.8 years (27-57 years) and a mean body weight of 69.8 kg (52-91 kg). The SEM chair (Simulator for Evaluation and Measures, Promed Inc.) was used to obtain six different sitting positions (figure 1). The experimental sequence included a total of 8 sitting configurations, with 2 returns to the neutral position.

- P1: System tilt 0°, Seat-to-back angle 100°, (Neutral position);
- P2: System tilt 25°, Seat-to-back angle 100°;
- P3: System tilt 35°, Seat-to-back angle 100°;
- P4: System tilt 0°, Seat-to-back angle 100°, (Return to P1);
- P5: System tilt 0°, Seat-to-back angle 120°;
- P6: System tilt 25°, Seat-to-back angle 120°;
- P7: System tilt 35°, Seat-to-back angle 120°;
- P8: System tilt 0°, Seat-to-back angle 100°, (Return to P1).

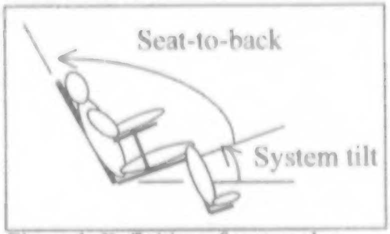

Figure 1: Definition of seat angles.

The subjects sat on a 2-inch flat-foam cushion, with their pelvis placed on the SEM as far back as possible, without compromising their stability. The seat depth was adjusted for every subject so that a 4 cm space was left between the front of the seat and their legs. The footrests were adjusted so that the thighs were parallel to the seat cushion, a headrest was used, and the subjects' arms remained on the armrests during the whole experimentation. For one subject, only the first four positions were done because of technical problems encountered. With the help on an occupational therapist, external markers were placed on eight anatomical landmarks, based on the result of Maltais et al.(5): right and left femoral condyles, greater trochanters, anterior superior iliac spines (ASIS) and acromions. The three-dimensional coordinates of the markers were obtained using 8 video cameras and the ExpertVision software (Motion Analysis Corporation). Three geometric parameters, defined below, were calculated to characterize the subjects' postures in the sagittal plane. The mean value of the left and right angles were calculated for each parameter. The back and seat angles of the SEM were also measured with the Motion Analysis System.

- *Trunk*: angle between the seat surface and the line joining the acromion and the ASIS;
- *Pelvis*: angle between the seat surface and the line joining the greater trochanter and the ASIS;
- *Hip*: angle between the lines joining the ASIS, the greater trochanter and the femoral condyle.

Three statistical analyses were performed to determine the influence on segment orientations of: 1-system tilt (P1-P2, P1-P3, P2-P3, P5-P6, P5-P7, P6-P7), 2-seat-to-back angle (P1-P5, P2-P6, P3-P7), and 3-the return to the neutral position (P1-P4-P8). Student t-tests were used with a p-level of 0.05. Correlation between backrest angle (to the horizontal) and the parameters were also computed.

RESULTS

Figure 2 presents parameter variations with respect to the neutral position P1. The analysis conducted for the study of the tilt angle (analysis 1) revealed that, for the pelvic and hip angles, statistical differences were observed between the 0° tilt and the 25-35 tilts (P1-P2, P1-P3, P5-P6, P5-P7), but not between the 25 and 35° tilts (P2-P3 and P6-P7). Therefore, system tilts of 25 and 35° resulted in an increase of posterior pelvic tilt and hip angle of approximately 5 and 6°, when the seat-to-back angle is at 100° and 120° respectively. For the trunk angle, no statistical differences were noted between the different tilt angles, regardless of the seat-to-back angle. As shown in figure 2 (analysis 2), a seat-to-back angle increase of 20° results in a significant increase in all parameters. When the system tilt is maintained a 0° (P5), the increase noted is approximately 22° for the trunk angle, and 16° for pelvis and hip. When the system tilt angle is fixed at 25 or 35° (P6, P7), all the parameters show an increase of approximately 22°, including the pelvic and hip tilts. The return to the neutral position (analysis 3) showed no significant changes between the parameters calculated in P1 and those from P4 and P8, despite the 2° increase noted at P8 on fig.2. Therefore, the back and forth seating positions did not influence the final sitting posture.

The correlation analysis between the backrest angle and the parameters revealed that the two are highly correlated (r = 0.99 for the trunk, ~0.98 for the pelvis, 0.83 for the hip).

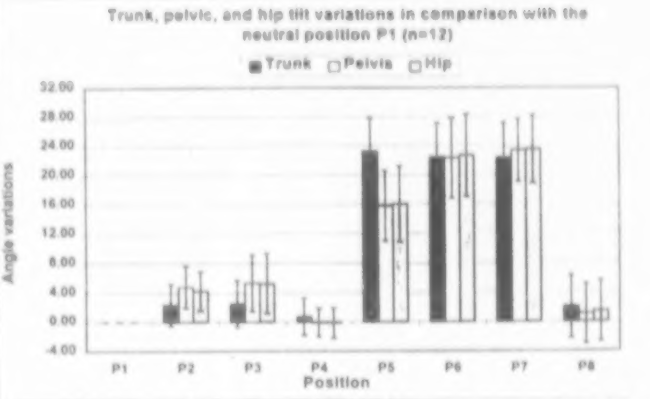

Figure 2: Parameter variations with respect to the neutral position P1 (defined as zero). Positive values mean an increase in posterior tilt, and negative values mean an increase in anterior tilt.

DISCUSSION and CONCLUSION

The results of the study showed that a system tilt increase of 25 or 35° influences only the pelvic tilt and hip angle, which increased of approximately 5° posteriorly (for seat-to-back angles of 100 and 120°). No significant changes were noted for the trunk. A seat-to-back increase of 20° (for a 0° system tilt) increased the trunk angle of 22°, and the pelvis and hip angles of 16°. Therefore, the pelvis and the trunk react differently when the seat-to-back angle increases, which confirms the findings of Nwaobi(6). Nevertheless, a strong correlation was found between the backrest angle and the three parameters. These results confirm the first hypothesis, which stated that changes in the wheelchair orientation modify the trunk, pelvis and hip angles (except for the trunk angle with system tilt increases). No postural changes were noted with the two returns to the neutral position after the imposed sitting modifications of this study, which doesn't confirm the second hypothesis. Combining the results of Gilsdorf (1) to this study, back and forth seating position affects the pressure distribution but not the posture.

This study showed that the trunk angle follows the seat-to-back angle, with little but not significant variations when tilted, while the pelvis and hip orientations are influenced by seat-to-back and tilt angles. It was found that increases in these two seat angles tend to posterioly tilt the pelvis. But further studies must be conducted, with multiple back and forth positions, to verify or contradict the two hypotheses made.

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STABILITY EVALUATION OF THE USER IN SEATING DEVICES USING A KINEMATIC MODEL

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ABSTRACT

Kinematic computer modeling of the user in the wheelchair was developed to simulate lateral trunk stability provided by different backrests using ADAMS software. The model was composed of ellipsoids and parallelepipeds, linked by simple articulations. Interface between human body and seating devices is modeled with contact elements. Simulations of a user and his wheelchair on a tilted pathway was performed. Different indices were measured and compared to those of an experimental study. Two backrests were then compared in terms of stability. Preliminary results show that the approach is feasible and appropriate to compare various seating devices.

BACKGROUND

Lateral trunk instability is a common problem among wheelchair users. This instability is often the cause of trunk alignment problems. Many backrests were designed to provide adequate lateral support. However it is difficult to evaluate the stability provided by these backrests. Most of the work in the field of seating addresses the wheelchair stability itself [1,4,5]. Axelson and Chesney [2] have proposed a method to evaluate forward and lateral stability provided by assistive devices, defined as the maximum distance the subject could reach with the dominant hand holding a weighted object. However, this method does not consider the stability of the user when using his wheelchair. An experimental method was developed by Parent et al. [6] to determine and compare lateral stability provided by different backrests. The user was asked to drive his powered wheelchair at a constant speed on a horizontal pathway composed of an horizontal plane, a twisted part and a 10° laterally inclined plane. This approach implies many trials and manipulations for the evaluation of stability of each subject. The purpose of this paper is to present a computer modeling approach that was developed and used to simulate the experimental method of Parent et al.[6] in order to test, by simulation, different types of backrest or design improvements of seating aids.

METHOD

The model was developed using the ADAMS software (Mechanical Dynamics Inc.). The wheelchair and the subject were modeled by parallelepipeds and ellipsoids elements. The human body (android) is represented by 15 rigid segments (figure 1) linked by simple articulations (spherical and revolute joints). The mass and inertia of each segment are adapted from a 90th percentile HYBRID III mannequin [3]. These parameters can be modified to fit the anthropometric measures of a given subject. The geometry of the seating aids was represented with a discrete number of rectangular surfaces, which dimensions were calculated from surface measurements obtained with a mechanical arm 3D digitizer (Microscribe 3D, Immersion

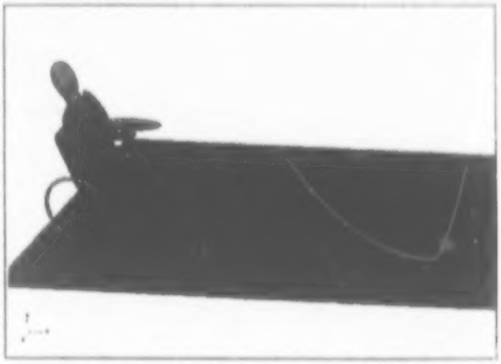

Figure 1. Geometrical model of the android, wheelchair and pathway.

Corp.). One flat cushion (25 surfaces) and two backrests (20 surfaces) were modeled. For each of these surfaces, a contact element was introduced between the android and the seating aid, which allows the specification of stiffness, damping and tissue deformation of cushion and buttocks. Figure 1 shows the model and the pathway.

In order to reproduce the experimental conditions of Parent et al., displacement of the user in his wheelchair was simulated at a constant speed (1.4 m/s) on a horizontal plane followed by a twisted plane and a 10° laterally inclined plane. Two indices were then calculated : the Trunk Lateral Tilt (TLT) i.e. tilt of the trunk in the frontal plane, and the Trunk Transverse Rotation (TTR) i.e. the shoulders rotation in the transverse plane. Similar indices were obtained from the experimental studies of Parent et al [6]. These indices and those obtained from the simulation with the standard backrest were compared for validation purposes. Two backrests were compared : a "standard" backrest composed of a 7.5 cm depth contoured lateral support located at the middle height of the back and a "sharper" backrest (prototype developed by Orthofab Inc.) composed of a 9 cm depth contoured lateral support located in the upper part of the back.

RESULTS

Results obtained by the simulation and experimental approaches for the "standard" backrest are presented in figure 2. TLT values for both studies seem quite similar along the pathway. The presence of a sudden change in the transition zone (between the twisted and laterally inclined planes) is shown as abrupt increase of the TLT values, unless there is a slight gap between the change of orientation due to articulation damping. However there is a difference of 1.5 degrees between maximal amplitudes of simulated and experimental curves when the subject reached the inclined part of the pathway. On the other hand, TTR evolution is slightly different especially in the transition zone. A difference of 3.8 degrees is observed, probably due to experimental initial asymmetrical trunk rotation of the subject which was close to 4 degrees.

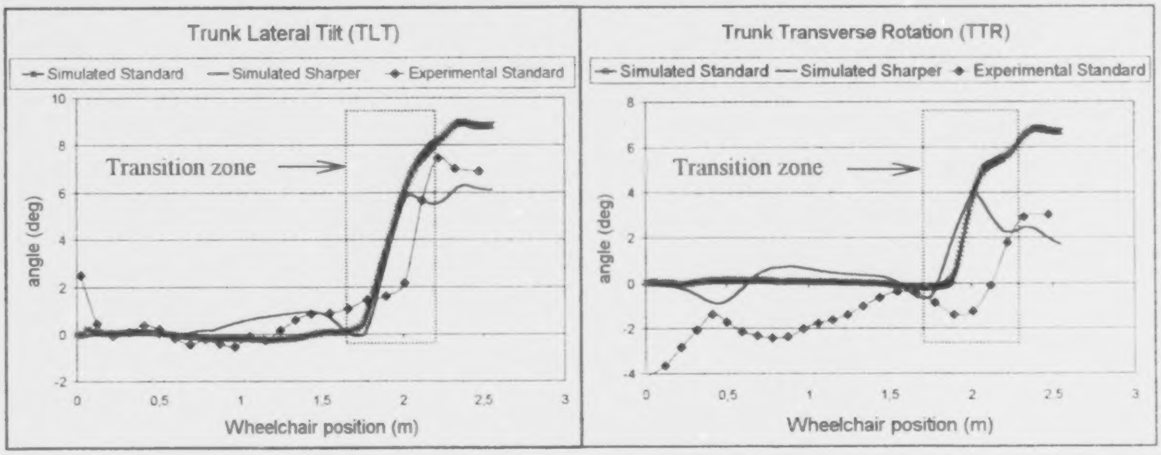

Figure 2. Geometrical indices computed from simulations for the two different backrests and from the experimental study of Parent et al.

A second set of results was obtained comparing two different backrests (figure 2). For the TLT parameter, the "sharper" backrest allows less lateral displacement then the "standard" backrest (6.3° against 8.9° when maximal amplitudes on the inclined plane are compared). The TTR parameter is more difficult to evaluate, the curves being different even if the transition zone is always present. In amplitude the "sharper" backrest shows lower values of trunk rotation (4° against 6.8° for the maximal amplitudes on the inclined plane).

DISCUSSION

The aim of this study was to develop a model to compare various seating devices. Trunk indices obtained by simulation are close to those obtained by experimental study, which supports the feasability of the approach. Improvements are still in progress to better estimate trunk stability. Joint properties have a great influence on the computer simulation results. These properties may vary with muscular activity and are difficult to approximate. In addition, HYBRID III model is a rough approximation of the anthropometry of the subject who volunteered in the experimental study.
The geometric indices used for the comparison of lateral stability provided by the two backrests seem to be relevant for this evaluation, nevertheless other indices of the lateral stability can be considered to improve the comparison. Based on the kinematic simulation, it seems that the sharper backrest provides more lateral stability than a standard backrest. Others studies should be done to compare more deeply the stability provided by these backrests in different situations in order to reinforce the results presented in this paper.

Finally, even if some improvements of the model are in progress, this study has shown that this kinematic computer approach is an adequate tool to test of different types of backrest or to improve the design of seating aids.

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MEASUREMENT OF THE STATIC REAR STABILITY OF OCCUPIED WHEELCHAIRS IN THE CLINICAL SETTING

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ABSTRACT

The objective was to evaluate platform testing of the static rear stability of wheelchairs occupied by their users, from the perspective of its measurement properties, safety and comfort. We studied 97 wheelchair users, measuring static rear stability, reliability, validity, sensitivity, specificity, predictive values and likelihood ratios, using dynamic stability as the criterion measure. In the clinical setting, the ISO platform test of static rear stability has good to excellent measurement properties, is safe and well tolerated. However, static-stability testing in this setting should be performed in the context of a comprehensive evaluation of wheelchair safety and performance.

BACKGROUND

In the United States, there are about 50 wheelchair-related deaths each year (1) and over 36,000 nonfatal wheelchair-related accidents per year that are serious enough to cause the injured person to seek attention at an emergency department (2). Instability is a factor in the majority of cases. Despite the positive impact that the ISO platform test of static stability (3) has had in the manufacturing and research arenas (4), the clinical evaluation of the stability of wheelchairs occupied by their intended users has surprisingly remained a qualitative one.

RESEARCH QUESTION

The objective of this study was to evaluate platform testing of static rear stability in the clinical setting, from the perspective of its measurement properties, safety and comfort.

METHODS

We studied 97 wheelchair users, measuring their static rear stability using the newly revised ISO standard (3) under five conditions: with the brakes locked, with the user leaning forward and backward, with an antitip device in place and with the brakes unlocked. We evaluated reliability, validity, sensitivity, specificity, predictive values and likelihood ratios. For the criterion measure, we used an ordinal scale (0-4) of dynamic rear stability (5) while the wheelchair user negotiated 6 environmental challenges: reaching and leaning backwards, accelerating forwards and decelerating while moving backwards, each on the level and on a 5-degree incline. For the two-by-two tables, we dichotomized the static- and dynamic-stability values into positive (abnormal) and negative (normal) test results. We defined a positive dynamic-stability test as a total value of < 24 on the six dynamic-stability tasks. To choose a cutoff value for the static-stability tests, we considered the tradeoffs between sensitivity and specificity, choosing to maximize the product of the two to ensure that they would be simultaneously high.

RESULTS

There were no adverse events and the subjects found the tests comfortable, non-frightening and indicated that they would be willing to have the tests again. The test-retest reliabilities ($n = 18$-24) were all > 0.93. Regarding content validity, we identified two problems when adapting the ISO method for clinical testing: i) when a wheelchair user used the feet for propulsion and ii) in 7 of the 59 antitipper tests attempted, the antitipper did not prevent the wheelchair from tipping over backwards, so that the ISO-defined endpoint (unweighting of the rear wheels) could not be determined. Construct validity was confirmed by the fact that leaning forward increased rear stability by 75% in comparison with the brakes-locked values, leaning backward decreased it by 18%, antitippers increased it by 54% and unlocking the brakes increased it by 64% ($\underline{p} < 0.0001$). The test's good concurrent validity was demonstrated by the Spearman's rank correlation values between the static-stability values and the total dynamic-stability values which ranged from 0.29 to 0.65. Sensitivity ranged from 46 to 86%, specificity from 59 to 78%, positive predictive values from 76 to 86%, negative predictive values from 42 to 69%, positive likelihood ratios from 1.56 to 2.95 and negative likelihood ratios from 0.22 to 0.71.

DISCUSSION

The test-retest reliability of static-stability testing was excellent. Both of the content-validity difficulties with the ISO method were easily correctable. When a patient has his/her feet on the platform during testing (e.g., due to the absence of footrests), the endpoint should be when the force becomes zero under the feet rather than under the front wheels. Regarding the antitipper section of the ISO method, we recommend a slight change in the ISO description of the endpoint – when the antitippers fail to prevent the wheelchair from tipping over, so that the usual endpoint of unweighting of the rear wheels cannot be determined, the brakes-locked value should be recorded. In this way, the added stability from the use of the antitip devices (the antitipper minus the brakes-locked tipping angles) will be zero, as it should be. For construct validity, we found that the static-stability values responded appropriately to situational changes. Regarding concurrent validity, the relationship between static and dynamic stability was good.

Although the sensitivity, specificity, predictive values and likelihood rations were good, in the clinical setting we do not recommend the use of a firm cutoff value for normal/abnormal stability. Rather, we suggest that clinicians recognize that the risk of a rear-tipping accident is roughly an inverse function of the measured rear stability, but that this risk is also influenced by the ability of the wheelchair user to anticipate such accidents and take steps to prevent them (e.g., by leaning forward). A wheelchair user will often be prepared to accept lower rear-stability values as an appropriate trade-off for better performance.

Although we originally included the dynamic-stability tests only to permit the evaluation of the concurrent validity of static-stability testing, our respect for this technique grew during the study. The discrete event anchors of the ordinal scale are well defined and the scale reflects clinically meaningful distinctions, with one exception. Making the distinction between a "transient tip" (grade 3) and a "transient antitipper-limited tip" (grade 2) suggests that a subject would sometimes be disadvantaged by using an antitip device, whereas the use of a properly designed and adjusted antitip device is beneficial, from the stability perspective, if it prevents a more dangerous partial or full tip. The transient antitipper-limited tip category should be eliminated from the scale, using instead the four-point scale that has been reported earlier (4). We believe that an evaluation on an obstacle course should be used as a routine screening test for wheelchair stability (as well as performance) and that the platform test of static stability should only be used when more sensitive measures are needed.

We conclude that, in the clinical setting, the ISO platform test of static rear stability has good to excellent measurement properties, is safe and is well tolerated by patients. Static-stability testing in the clinical setting should be performed in the context of a comprehensive evaluation of safety and performance.

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A COMPARISON OF POWER WHEELCHAIR STABILITY USING ANSI/RESNA STANDARDS

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ABSTRACT

The purpose of this study was to utilize the ANSI/RESNA Wheelchair Standards to determine the static and dynamic stability, as well as braking distance of five different types of popular power wheelchairs. Significant differences were observed between the wheelchairs for all three ANSI/RESNA tests. The Quickie P200 and Action Storm are the fastest wheelchairs, but also the most unstable and have the longest braking distances. The Pride Jazzy, Permobil Chairman, and Everest & Jennings Lancer 2000 are more stable but slower wheelchairs.

INTRODUCTION

Power wheelchairs provide a vital means of mobility for thousands of people with disabilities in the United States, as well as the entire world. A variety of different models are available and range in price from a few thousand dollars to over twenty thousand dollars. The goal of ANSI/RESNA Wheelchair Standards is to provide a set of tests that can be utilized to compare the performance of different types of power wheelchairs. There have been other studies that have compared the performance of power wheelchairs (1,2), however; technological advances in recent years have outdated these results.

Five different types of power wheelchairs were chosen for testing. Three wheelchairs of each type were purchased in order to perform statistical analysis. The wheelchairs compared in this study include the Everest & Jennings Lancer 2000, the Sunrise Medical Quickie P200, the Pride Healthcare Jazzy, and the Permobil Chairman. We hypothesized that (1) static stability results would not be significantly different; (2) dynamic stability results would show no significant differences; and (3) there would be no significant difference between the types of wheelchairs when tested for effectiveness of brakes.

METHODS

The testing performed during this study was in accordance with sections 1, 2, and 3 of the ANSI/RESNA wheelchair standards (3). These sections include determination of static stability, determination of dynamic stability of electric wheelchairs, and test methods and requirements for the effectiveness of brakes, respectively.

The static stability of each wheelchair was determined by inclining a horizontal test plane until the uphill wheels of the wheelchair lost contact with the surface. Each wheelchair was tested in its most stable and unstable configurations facing uphill, downhill, and sideways.

The dynamic stability of each wheelchair was tested on level surface, as well as slopes of 3°, 6°, and 10°. The stability was determined under various circumstances; starting forward uphill, braking after traveling forward uphill, braking after traveling backward downhill, braking when traveling forward downhill, turning on a downhill slope, and traveling from a sloped to level surface. The stability was rated using a four point scale with a 4 signifying no tipping, 3 –transient tipping, 2- transient tipping with antitipper contact, 1- tipping with the wheelchair/scooter remaining on the antitippers, and 0- full tip.

The effectiveness of brakes was also conducted on 0°, 3°, 6°, and 10° slopes. Braking distances forward downhill and backward downhill were recorded under the following conditions; joystick release, joystick reverse, and power off. Three trials were conducted for each condition and the final score was determined from the average of the three tests. Analysis of variance (ANOVA) with levels of significance of $p \leq .05$ were used to test the three hypotheses.

RESULTS

The results for this study show that there are significant differences in the stability and braking distance of the five different types of power wheelchairs (Table 1). There were significant differences ($p < .05$) between the wheelchair types with respect to facing downhill (most stable configuration), facing uphill (most & least stable), and facing uphill-Antitippers (most & least stable). There were no significant differences ($p > .05$) with respect to facing downhill (least stable) and lateral (most & least stable)

Table 1: Tip Angles of Test Wheelchairs.

Static Stability	Facing Downhill		Facing Uphill		Facing Uphill Antitip Devices		Lateral	
Wheels	Unlocked		Locked		Locked		Locked	
	Most	Least	Most	Least	Most	Least	Most	Least
E&J 1	28.9°	26.4°	19.7°	15.7°	20.3°	18.5°	17.4°	17.4°
E&J 2	33.8°	29.1°	19.5°	17.8°	27.9°	22.8°	19.3°	17.8°
E&J 3	34.7°	28.2°	19.3°	16.8°	22.2°	21.1°	18.6°	17.7°
Quickie 1	27.9°	23.2°	5.1°	5.0°	11.1°	9.4°	24.8°	24.5°
Quickie 2	26.2°	22.5°	9.1°	4.8°	12.4°	6.2°	17.3°	16.9°
Quickie 3	27.1°	20.9°	5.7°	5.0°	8.0°	7.0°	17.8°	16.7°
Action 1	19.7°	16.5°	22.5°	19.6°	23.3°	20.3°	16.2°	14.8°
Action 2	25.9°	22.7°	19.8°	18.8°	20.4°	20.0°	17.6°	16.8°
Action 3	29.7°	19.6°	20.3°	19.2°	21.6°	12.4°	18.7°	15.6°
Pride 1	23.2°	29.4°	25.6°	23.7°	35.9°	30.1°	18.7°	19.6°
Pride 2	11.0°	10.6°	20.8°	20.5°	33.4°	23.5°	16.1°	14.7°
Pride 3	11.4°	10.8°	19.5°	18.9°	24.7°	20.8°	14.7°	14.7°
Permobil 1	32.1°	17.5°	37.3°	30.5°	N/A	N/A	18.6°	20.3°
Permobil 2	31.5°	19.3°	37.3°	30.5°	N/A	N/A	21.2°	20.8°
Permobil 3	33.6°	18.5°	37.8°	29.3°	N/A	N/A	20.6°	19.3°

Dynamic stability scores were significantly different for many of the test conditions. There were significant differences ($p < .05$) for starting forward on a 0°, 3°, 6°, and 10° slope and braking while traveling backward by pushing the joystick forward, as well as killing power, on all slopes. There were also significant differences for braking while traveling downhill for all conditions on 6° and 10° slopes, as well as braking while traveling uphill, all conditions, on a 10° slope. The wheelchair types were also significantly different when braking while traveling uphill (joystick release) on a 3° slope, as well as braking while traveling downhill (power off) on a 3° slope. Finally, there were significant differences when braking while traveling backwards (joystick reverse and power off) on a level test surface. The scores for the Action Storm and Quickie P200 were consistently lower than the other wheelchairs.

The results of the effectiveness of brakes show significant differences ($p < .05$) for every braking condition. These conditions include stopping the wheelchair by (1) releasing the joystick, (2) reversing the joystick, and (3) turning the power off. The wheelchairs are tested in both the forward and backward direction using these braking conditions. These tests are performed on a level surface, 3° slope, 6° slope, and a 10° slope. The braking distances for the Action Storm and Quickie P200 are considerably longer than the distance of the other wheelchairs.

DISCUSSION

The results of the ANSI/RESNA testing show that there is a significant difference in many of the performance standards associated with power wheelchairs. The static and dynamic stability of the Quickie P200 and the Action Storm are very different than the other three types of power wheelchairs. However, these two wheelchairs are considerably faster than the other types and are designed for very active people. The Permobil Chairman and Pride Jazzy are both front wheel drive wheelchairs. This enables them to perform tight turns and increases their maneuverability, but it also reduces their maximum speed, and thus makes them more dynamically stable (4). Although the Quickie and Action wheelchairs are less dynamically stable, antitip devices prevent them from completely tipping over. The antitippers on both wheelchairs often come into contact with the test plane, and the wheelchairs are actually intended to function with six wheels instead of four.

The braking distances of the wheelchairs are also representative of their intended use and greatly affect the safety of the user (5). Due to their speed and design, the Quickie P200 and Action Storm usually require a longer distance to brake on different slopes. The Pride Jazzy and Permobil Chairman require the shortest stopping distance, and the E&J Lancer falls into the mid-range.

CONCLUSIONS

We conclude that the five different types of power wheelchairs used for this study are significantly different with respect to static stability, dynamic stability, and effectiveness of brakes. The ANSI/RESNA Wheelchair Standards are a very useful tool to help analyze the different types of wheelchairs that are available and determine which model is right for a particular individual. It is important for a user to know the parameters of his or her power wheelchair in order to prevent serious injury, as well as make sure that they are getting the best value for their money.

The research performed in this study is part of an ongoing investigation. All fifteen of the power wheelchairs will be tested according to the complete set of ANSI/RESNA Wheelchair Standards. This will allow for determination of fatigue life as well as cost analysis of the different types of wheelchairs.

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A SELF-PROPELLED MOBILITY DEVICE FOR SOFT SURFACES

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ABSTRACT

Wheelchair users often encounter problems when propelling across uneven soft surfaces such as sand or loose gravel. Research conducted at Beneficial Designs with individuals propelling manual wheelchairs on a soft surface revealed that none of the subjects were able to traverse 50 meters across soft sand. Current beach chair technology does not permit individuals who use manual wheelchairs to independently propel and maneuver. This study describes the development of a prototype device with the option of independent mobility on soft surfaces. Preliminary user testing showed an improved ability to independently propel and turn on soft surfaces. After improvement of the prototype, other applications will be evaluated to determine the effectiveness of the chair in snow and other soft surfaces.

BACKGROUND

Many individuals rely on their wheelchair for daily transit, during which they encounter and traverse different types of surfaces. Manual wheelchair users have the ability to propel across these different surfaces without much effort. But if soft surfaces are encountered such as sand or snow, the typical daily wheelchair does not function well. Research currently being conducted at Beneficial Designs with individuals propelling manual wheelchairs on a soft surface has revealed that none of the subjects were able to traverse 50 meters across soft sand. Various beach chairs have been on the market to assist wheelchair users in maneuvering across these surfaces that are neither firm nor stable. With one chair (Landeez), a horizontal bar at the rear of the seating system presents a potential hazard to the user. Furthermore, the seating is high off the ground and the tires are difficult to reach for self-propulsion. Another chair (Deming) requires extensive and expensive construction to enable users to self-propel. Other attendant-propelled models are designed to seat the occupant high above the ground, which makes it hard for the user to reach the ground and interact with the natural surroundings. Another inconvenience of current beach chair technology is the instability or tippiness experienced by the user when transferring to and from the beach chair. Identifying these disadvantages led to the creation of a list of design criteria necessary for developing a soft surface mobility device that is self-propelled, comfortable and safe to use.

HYPOTHESIS

This design study is based on seating that creates a low center of gravity. The prototype device can be propelled independently and offers the occupant a better opportunity to interact with the natural surroundings than do currently available products. Design criteria were established to make the soft surface mobility device comfortable and easy to propel. The developed product concept improves upon currently available beach chairs by providing the following features:

- Ability to self propel the chair over various soft surfaces which are difficult to access
- Ability to reach the ground (sand, water, shells, rocks and snow) while seated
- Ability to independently place the chair in a reclining position to relax
- Ability for an assistant to propel the chair in case of limited upper extremity function

METHOD

Computer design software (Form-Z for Apple Macintosh) was used to design and visualize a 3-dimensional concept and then a prototype of the soft surface mobility device was built. Because the design concept was to be tested and used in a sandy and salty environment, PVC tubing and PVC connectors were used to build the frame of the prototype. Two 18-inch Rolleez wheels and two 11-inch Rolleez wheels were used. PVC tubing was used to construct the frame and seating system. One-inch webbing and two plastic buckles were used to adjust and lock the backrest angle and 2-inch webbing was used for the seat and for positioning of the feet.

RESULTS

The design of the frame is dynamic to allow the device to flex and pivot as it follows the terrain. It consists of two parts: one that tracks over the surface and the second a seating system. The forces acting perpendicular on the PVC and causing unwanted bending of the PVC are minimized. Distribution of the weight of the seating system over the center wheels brings the chair into balance and makes it easy to steer. The prototype allows the user to pop a wheelie for turning. The rolling part contains two 18-inch and two 11-inch Rolleez wheels, which prevent the device from sinking into the surface material when loaded with the occupant weight. The front and rear wheels connect via one center axle through the main wheels, which pivot around the center wheel axle. This setup prevents the seating system and the occupant from experiencing large vertical movements on uneven surfaces. The front of the seating system connects to the front wheel axle with two tubes. The long frame length to the front wheel decreases the vertical movement when an obstacle is encountered (Figure 1a, 1b). If the rear wheel of the soft surface mobility device encounters an obstacle, the bracket that is mounted to the wheel and center axle will raise to the top of the obstacle (Figure 1c, 1d).

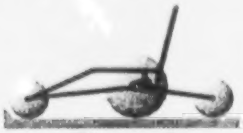
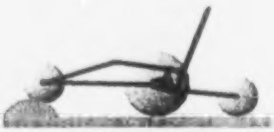


Figure: 1a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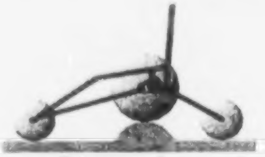
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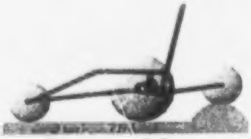
Figure: 1d

Because the seating system is not directly mounted to the rear wheel assembly, it will raise less, resulting in a comfortable and easy ride for the occupant. Two connector plates mounted to the rear wheel connect the seating system and the center wheel axle and make the mobility device stable in the lateral direction (Figure 2, Table 1).

Table 1. Characteristics of the Soft Surface Mobility Device

Description	Dim. of prototype	Description	Dim. Of prototype
Overall length including tires	60 in.	Size large tires	18in. x 8in.
Overall width including tires	36 in.	Size small tires	11in. x 7in.
Overall height	35 in.	Total pressure surface of small tires (3.5in.)	19 in.^{2}
Seat height	15-16 in.	Total pressure surface of big tires (ellipse 5.5in. x 8in.)	138 in.^{2}
Seat depth	18 in.	Weight of device including tires	35 lb.
Seat width (outside tubing)	17.5 in.	Total footprint	314 in.^{2}
Backrest height	20 in.	Average pressure of mobility device and occupant (150 lb) on surface	314/(35+150)= 1.6 lb/ in.^{2}
Backrest width	12 in.		

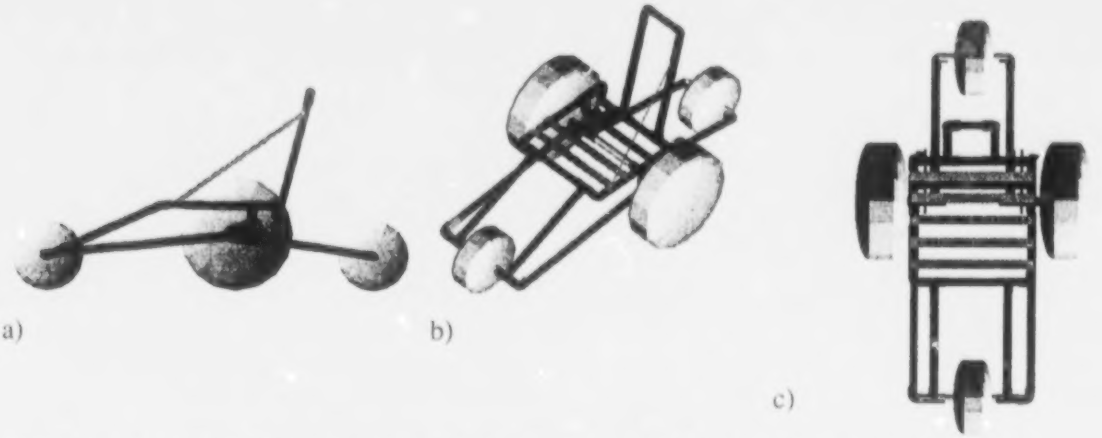

Figure 2: a) Side, b) 3-Dimensional and c) Top view of Soft Surface Mobility Device

DISCUSSION

After a preliminary evaluation of the prototype with one wheelchair user and one non-disabled person, the following suggestions for improvement were found:

The front frame shows visual bending; aluminum or PVC with a bigger wall thickness should be used or the rolling part of the frame should be made from aluminum and the seating system from PVC. A PVC tube could be added between the front of the seating system and extending rearward to the center wheel axle. The need for adjustability of the seating system in the forward and rearward direction should be evaluated for individuals of different weight and size. The amount of incline of the backrest should be evaluated as well as the width of the webbing belts and buckles. The belts might be too small for their purpose and lateral support padding might be necessary in combination with a wider belt. The method of mounting the backrest to the seat frame and the use of the adjustment belts and buckles must be evaluated for strength and user comfort. The wall thickness of the KYDEX connector plates should be reinforced to improve the stability around this connection point. A mechanism for pushing the chair by an assistant needs to be added. The large center wheels are used as pushrims to propel the device. The strength needed to propel the device in certain circumstances might be unacceptable or impossible for some users. The strength needed to propel the mobility device should be examined. Different propulsion techniques must be explored and evaluated, such as using paddles, handlebars or sand poles to maneuver the mobility device. Also, different tires with a different tread pattern could be useful to increase the friction between tires and hands. Mounting a pushrim on the current wheels might be functional for some users. After improvements are made to the prototype according to these suggestions, a product concept will be ready for testing with various wheelchair users. The final issue that should be evaluated is how the chair can best be manufactured. This study produced a promising concept that provides an affordable opportunity for wheelchair users to independently propel across different surfaces, an opportunity which is not possible with current technology.

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WHEELCHAIR DROP-SEAT SLOTBOARD TO SUPPORT THE RESIDUAL LIMBS OF PEOPLE WITH TRANSTIBIAL AMPUTATIONS: SHORT-TERM EXPERIENCE

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ABSTRACT

People with transtibial amputations commonly use wheelchair knee-extension devices, but all have limitations. We developed a new drop-seat slotboard device, the key improvements of which are lateral cutouts and L-shaped sliders that permit the seat to be dropped to or below the seat rails. We present the case reports of the first three elderly people with transtibial amputations to use the drop-seat slotboard. Although one subject with cognitive problems had difficulty in correctly placing the device in the wheelchair, otherwise the subjects and their clinicians found the new device to be safe, easy to use and not to interfere with transfers or wheelchair propulsion.

BACKGROUND

Knee-flexion contractures are common complications of transtibial amputations and are due in part to prolonged periods of sitting in a wheelchair with the knee flexed during the postoperative period. The methods used to prevent and treat knee-flexion contractures include wheelchair knee-extension devices-- solid, hinged, swing-away and slotboard designs (1-4) -- but each has limitations. We developed design criteria from a review of the literature, then used a focus group to validate and rate the criteria (5). The focus group concluded that, of the four existing classes of devices, the slotboard best met the design criteria (5). We then modified the slotboard design to eliminate the principal limitations of existing slotboard devices. The key improvements are lateral cutouts and L-shaped sliders that permit the seat to be dropped to or below the level of the seat rails (Figure 1).

OBJECTIVE

The objective of this paper is to present our short-term experience with the new drop-seat slotboard, from the perspective of its ease of use, comfort and safety.

METHODS

The first three subjects to use the drop-seat slotboard were all actively involved in a tertiary-level rehabilitation program for patients with amputations. After a brief period of orientation and instruction (15 minutes or less), each subject used the device for at least one day. Thereafter subjects were interviewed regarding their observations and were evaluated while activating the sliders, putting the stump cushion on and removing it, removing the slotboard from the wheelchair and replacing it, transferring to and from the wheelchair and propelling the wheelchair (including the use of the feet).

RESULTS

Subject #1 was a 76-year-old male patient with a right transtibial amputation due to peripheral vascular disease. He had no difficulty pulling out and retracting the slider. He was able to position the stump cushion on the slider and attach it, then remove the stump cushion and store it. He experienced no difficulty in removing the slotboard from the wheelchair or replacing it. He was able to propel the wheelchair easily using his feet and to transfer to and from the wheelchair without assistance. He found the drop seat to be comfortable and safe. He stated that he would use the drop-seat slotboard if it was available because he felt that "he needed all the help he could get to keep his stump straight". In summary, the drop-seat device would appear to be a good choice for this subject.

Subject #2 was a 72-year-old female patient with a right transtibial amputation due to peripheral vascular disease. She had had a stroke in the past and had mild residual weakness of the left arm. Prior to the installation of the drop-seat slotboard, her wheelchair was equipped with a heavy rigid seat with a hinged stump support that was difficult for her (and her family) to remove when it was necessary to transport her wheelchair. With the drop-seat slotboard, she had no difficulty pulling out and retracting the slider. She was able to position the stump cushion on the slider and to attach it without assistance, then to remove the stump cushion and store it. Although she was able to remove the drop hooks from the seat rails unassisted, she had slight difficulty that she attributed to her 'bad left hand'. She encountered no difficulty when replacing the slot-board. She was able to propel the wheelchair easily using her feet and transferred to and from the wheelchair without assistance. During a weekend pass from the rehabilitation center, she was able to teach her family members how to remove and replace the slotboard for easy transport of the wheelchair. She found the drop-seat slotboard to be easy to use, convenient, safe and comfortable. She felt that she would definitely use the drop-seat slotboard if it was available. Indeed, when the researcher approached her to remove the drop-seat slotboard, she asked "Do you have to take it away?". In summary, the drop-seat slotboard would appear to be appropriate for this subject.

Subject #3 was a 72-year-old male patient with bilateral transtibial amputations due to peripheral vascular disease. He also had mild dementia of vascular etiology. He had no difficulty pulling out and retracting the slider. He was able to position the stump cushion on the slider and attach it without assistance and was able to remove the stump cushion without any problem. He had no difficulty removing the drop-seat slotboard from the wheelchair, but he was unable to safely replace it, failing to correctly place the drop hooks on the seat rails of the wheelchair. Once the seat was replaced for him, he replaced his wheelchair cushion in a manner that interfered with replacing the armrests. He was able to propel himself using his prostheses and he transferred to and from the wheelchair without assistance. He found the drop-seat comfortable and safe once it was in place in his wheelchair. He stated that he found the drop-seat slotboard useful for keeping his knees straight. He also stated that he would only use the drop-seat slotboard if his therapist recommended it because he found it difficult and confusing to insert it in the wheelchair ("there were too many things to remember"). In summary, the drop-seat slotboard would appear to be appropriate for this subject if a caregiver was available to assist with the removal and replacement of the device when it was necessary to fold the wheelchair needed for transport. Additional training might also have been helpful.

DISCUSSION

Although one subject (#3) with cognitive problems had difficulty in correctly installing the device, otherwise the subjects and their clinicians found the new device to be safe, easy to use and not to interfere with transfers or the ability to propel the wheelchair. That all three subjects were able to use their feet to assist in propelling their wheelchairs confirms that the seat heights were not artificially raised in the way that other slotboard devices do. The experience of subject #3 suggests

that the initial training in the use of the drop-seat slotboard should be individualized. Unless a subject can demonstrate the ability to safely carry out the essential tasks involved, he or she should not be provided with the device. Given these promising early results, we plan to carry out a long-term trial, issuing drop-seat slotboards to people with transtibial amputations immediately after surgery and subjects will continue to use them throughout their rehabilitation. We are working with a company that will make the drop-seat slotboard commercially available in 1999.

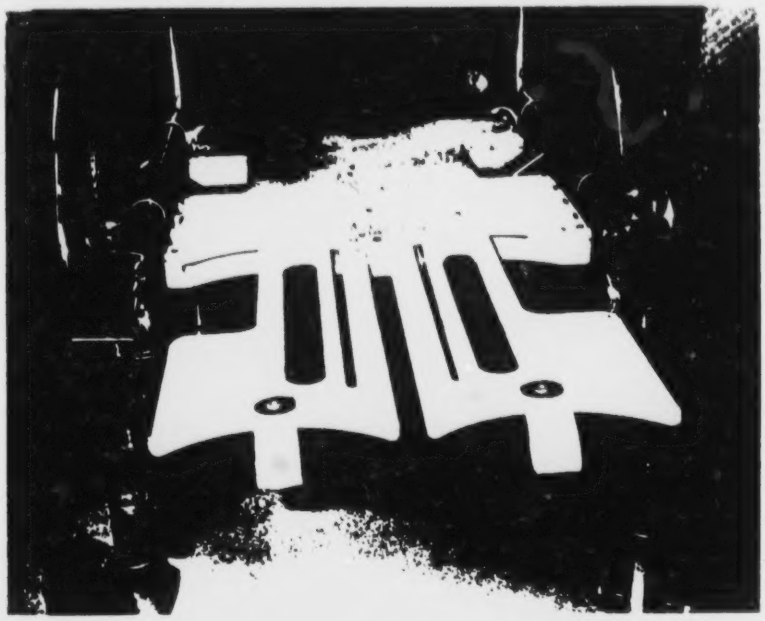

FIGURE 1: Prototype of the drop-seat slotboard, with both sliders extended and without cushions. Note that the seat surface is about 1" below the level of the seat rails.

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DESIGN DEVELOPMENT OF NEW PRONE CARTS

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ABSTRACT

Individuals with SCI who use a prone cart for mobility, have identified significant problems with current models. Specifically, prone carts interfere with activities of daily living (ADL) and with socialization. In addition prone carts lack adequate body support for comfort and safety. The impetus for a new design came from a veteran with SCI from the Zablocki VAMC. He formulated the idea of a prone cart with an articulated body support to improve comfort and safety. After several years of development, several prototypes designed and evaluated along the way, a new manual and a new powered prone cart are now ready for technology transfer. The new manual prone cart features an angle adjustable torso support; a contoured body support; a padded front deck with drink holder and elbow supports and a front pull-out storage drawer. The new powered prone cart has, in addition to the above features a joy stick controller for turning, braking, forward and reverse motion and two electric motors.

BACKGROUND

Once pressure sores develop, the patient must stay off affected areas until they are healed, in most instances, precluding the use of a wheelchair. Prone carts provide an alternative to prolonged bed immobilization for patients with ischial or sacral pressure ulcers who must lay on the side or in the prone position. Current prone carts lack adequate body support for comfort and safety and prevent their users from performing simple activities of daily living (ADL).

STATEMENT OF THE PROBLEM

The development of new a manual and powered prone cart designed to improve the quality of life of individuals of their users was a compelling need.

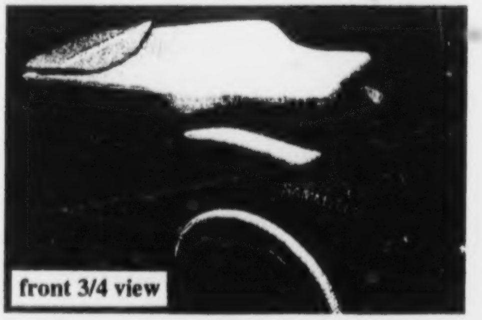
RATIONALE

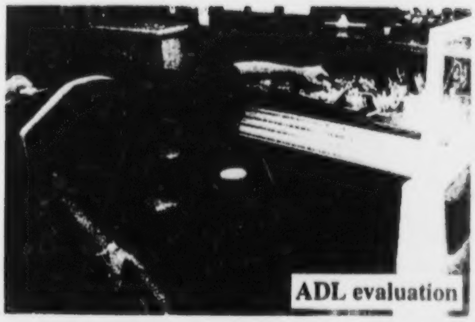
The idea for a new design came from a veteran with SCI, Mr. Emil (Sammy) Schnurr who has lived on a prone cart for more than 20 years and his caregivers at the Zablocki VA SCI Center. In an attempt to solve the problems associated with living on an horizontal cart, he formulated the idea for an angled cart so that users could look-up in a comfortable and painless position. Mr. Schnurr was in constant back pain from the elevated dorsal position he was assuming on his horizontal prone cart.

DESIGN and DEVELOPMENT

A team of MIAD Industrial Design students was assigned to turn the angled cart concept into a product. Working in collaboration with Sammy Schnurr, faculty and SCI clinicians, the students developed concept drawings and made a 1/4 scale model of a new prone cart. In recognition for their innovative design, an Award of Design Excellence was presented in 1993, by the Industrial Designers Society of America. From the award winning design, a design team was formed to refine the design and fabricate three carbon fiber prone cart prototypes. Named the SAMMY LS these prone carts were fabricated at the Milwaukee Institute of Art & Design.

The Sammy LS


front 3/4 view

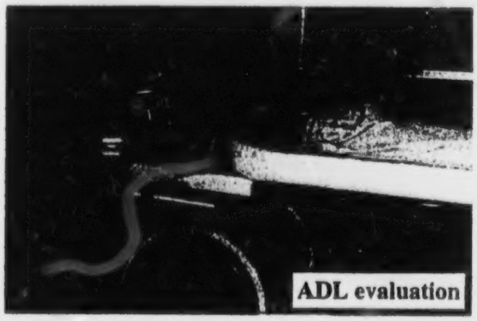

ADL evaluation

The Sammy LS featured a carbon fiber structure, manual propulsion with an angle adjustable body support hydraulically activated; a front deck with elbow rest; and a side pull-out storage.
Dimensions: Length: 142 cm -55.90" Height: 89 cm - 35"
Wheel to wheel width: 65 cm - 25.60" Wheel base: 95 cm -37.50"

Clinical evaluation: In addition to Mr. Schnurr who has lived on the first SAMMY LS since 1993, the other prone carts were evaluated at the Milwaukee and Tampa VAMC's
Based upon users feed back the SAMMY LS was found to be ideally suited for amputees and short individuals. Positive features: overall bold design; adjustable torso; contoured body support; front deck with elbow rest; good access to public phone; counter tops, etc. Negative aspects: when used by taller individuals, the cart was found difficult to propel because of rear weight displacement. Finally if the body support angled downward it gave users a sliding sensation.

Manual prone cart

rear 3/4 view


ADL evaluation

Based on the evaluation results of the SAMMY LS, it was decided to incorporate its best features into the next versions of prone carts. Designed with a tubular steel frame to cut the high cost of carbon fiber, the new of prone carts would be offered in two versions. A short version to accommodate small to average sized individuals and a long version to accommodate tall individuals.

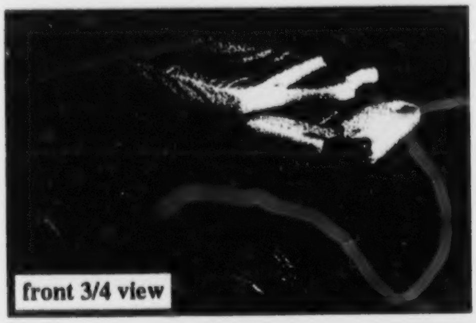
The features of the manual prone cart include: angled adjustable torso support, padded front deck for elbow support, a front pull-out storage drawer, contoured body support, and a 38 mm frame that forms an all around protective bumper including a foot guard.

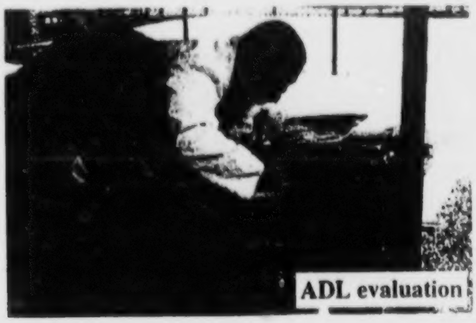
Dimensions: Long version: 203 cm -79.90" Short version: 178 cm -70"
Height: 76 cm - 29.90" Wheel to wheel width: 75 cm - 29.5" Wheel base: 106 cm - 42"

Propulsion: Manual with two composite 61 cm - 24" front wheels with 3.8 cm oversized hand-rims and two 20 cm - 8" swivel casters in the back.

Clinical evaluation: The new manual prone carts have been in clinical evaluation for a 24 month period at the SCI centers of the Tampa and Milwaukee VAMC, the Medical College of Wisconsin and in the community by numerous individuals with SCI. Positive features: overall pleasing design and color; wide hand-rims; adjustable torso support and the contoured body support; front deck with elbow rest; front pull-out drawer, overall height providing good access to public phone, counter tops, etc. Negative aspects: users indicated the need to include rear view mirrors to better gauge their motion going backwards.

Powered prone cart


front 3/4 view


ADL evaluation

To respond to the need of individuals who have difficulties self-propelling, the manual cart frame was redesigned to make a powered cart. The new powered prone cart is propelled by two electric motors and is operated by a joystick controller unit that controls speed forward & reverse, turning and braking.

Dimensions: Long version: 203 cm -80" Short version: 178 cm-70"
Height: 76 cm - 29.90" Wheel to wheel width: 77 cm - 30" Wheel base: 106 cm - 42"

Clinical evaluation: The new powered prone carts have been in clinical evaluation for a 12 month period at the SCI centers of the Tampa and Milwaukee VAMC and in the community. Positive features: overall pleasing design and color; torso and contoured body support; front deck with elbow rest; front pull-out drawer, overall height providing good access to public phone, counter tops, etc. Negative aspects: users indicated the need to include rear view mirrors to better gauge their backwards motion and the need for power adjustment of the torso support.

DISCUSSION-TECHNOLOGY TRANSFER

This project clearly illustrated that a team effort between users, clinicians, designers and a manufacturer, can lead to the successful design of new products. Final design changes reflecting the suggestions made during clinical evaluation will be incorporated in the production prone carts to be manufactured by Everest & Jennings.

ACKNOWLEDGMENTS

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DESIGN OF A HIKING CARRIAGE

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ABSTRACT

When active parents and children want to hike, accommodating equipment is scarce to nonexistent. Thus, a carriage to support a child with cerebral palsy during a hiking venture was pursued. Interviews, market and ergonomic studies, and a test model were used as the basis for the optimized design solution. A functional prototype was detailed and built. The prototype was tested on a basic level and was found to work successfully. In fact, the results were so remarkable that it was concluded to be a great design for even able-bodied children.

BACKGROUND

There are many debilitating circumstances which confine children to wheelchairs and limit their activities. A prominent example of this is cerebral palsy (CP), a symptom complex (1) caused by brain damage that generally occurs at the fetal or newborn stage. Cerebral palsy leaves children with motor symptoms that may include spastic paralysis, hypotonia, and epilepsy preventing them from walking and performing fine motor skills (2). Annually, "5,000 babies and infants are diagnosed" (1), and "about 1,500 preschool children acquire cerebral palsy through illness or accident" (1). In addition to CP being a common disability, the design team had unique access to an active family with a child diagnosed with CP. This yielded selecting cerebral palsy as the main population target for this design project.

Recreational activities that are enjoyed by many of us can be stifled or inhibited in families with CP-diagnosed children. Most outdoor activities are impractical with wheelchairs due to incompatible terrain, especially in the mountains. A good example of this is the popular recreational past time of hiking. Parents can enjoy this activity with their wheelchair-bound children by carrying them in a child-carrying backpack until about four years of age. Once the child reaches about 40-50 pounds, the child is too heavy to continually lift out of the wheelchair and carry on one's back. After a child reaches this point, accommodating equipment for outdoor activities is scarce to nonexistent. This resulted in the desire to design a new piece of recreational equipment to allow disabled children the unique and exciting opportunity to go hiking with their families, who would also benefit from the outdoor experience.

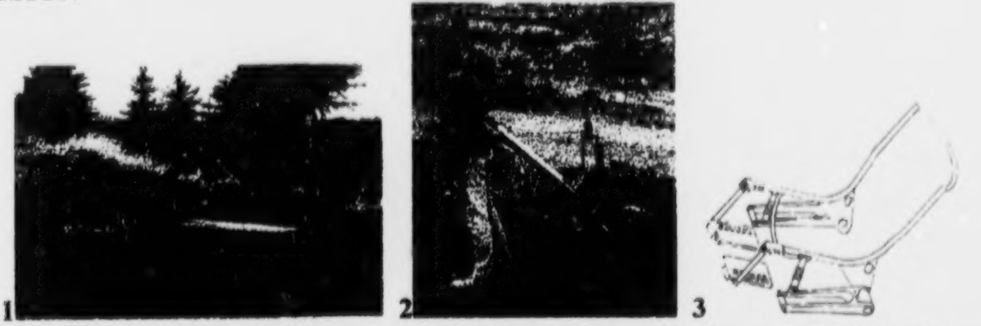
STATEMENT OF PROBLEM

The objective of this project was to design a hiking carriage for a 5-10 year old child with CP that is suitable for single-track trails and is operable by one adult.

DEVELOPMENT

The hiking carriage design was intended to be helpful and fun for families to use, thus much care was taken to clearly define the problem statement and understand the constraints that were part of the design. The design team conducted interviews with a family with a five year old son with CP, a physical therapist, manufacturers in the rehab design industry, and seating specialists. The results from these interviews were used, in combination with the engineering background of the design team, to develop a set of 15 design criteria, including quality guidelines and size restrictions. To assure uniqueness of design and to affirm that there would be no infringement on someone's rights, market and patent searches were pursued throughout the project life. Furthermore, ergonomic principles were used to balance the functionality of the hiking carriage for the broadest range of people possible with not being everything to everyone (3). Design alternatives were then expanded in thought and then evaluated. When the basic design was chosen, a test model was built. This model was used for ergonomic studies, including safety and comfort issues. Finally, the actual hiking carriage was designed in detail using engineering concepts and then built.

DISCUSSION



Figures: (1) overall side view of hiking carriage in the mountains, (2) the hiking carriage being used (note: the child in the carriage is not the age intended for this design), and (3) the seat frame shown with the trailing arm and suspension.

Design Solution

In general, the hiking carriage consists of a backpack, a drafting bar, a seat and two wheels, as depicted in Figure 1. The hiking carriage is about 4 feet long from the wheel axle to the back of the back pack and the seat bottom is about 20 inches off of the ground. Also, the hiking carriage currently weighs only about 30 pounds, due to most parts being constructed of high strength aluminum. The hiking carriage works very simply: the adult places the child into the seat and adjusts the features to fit their needs and connects the lap and foot straps. Then the adult puts the backpack on and adjusts the backpack straps to their desires. Finally, the adult can hike around pulling their child behind them, as seen in Figure 2.

The seat was designed to accommodate our model child with the ability to adapt to other children. Thus, the carriage has adjustable headrest and footrest heights and a pivoting knee angle. Additionally, the basic posture encouraged by this design is 90°-90°-90°, which is generally desired (4). However not everyone can use the 90°-90°-90° arrangement due to comfort levels, varying amounts of kyphosis/lordosis, proneness to pressure sores, and other varying concerns. Therefore, the fabric seat cover was designed to adjust size-wise for varying thigh and back lengths, as well as to allow varying slack amounts for different posture needs by means of loosening a nylon cord underneath the seat in the appropriate areas needed.

Another important feature of this design is the independent suspension system, which allows the carriage to give the child a softer ride through the rough terrain. The basic suspension concept is that of a supporting triangle, which begins with a trailing arm for each wheel, as seen in Figure 3. Each trailing arm attaches to a pivoting joint behind the seat and hangs down from this joint at approximately a 40 degree angle (from the bottom of the seat to the wheel hubs). Approximately 1-1.5 inches up the swing arm from the hubs, a single coil spring over a shock damper is pin jointed and is then pin jointed at the other end about 5 inches from the knee on the seat frame, completing the supporting triangle.

The safety features implemented include brakes and quick-release backpack straps and lap belt. Additionally, the center of gravity of the seat is near the wheel base giving the carriage high stability to decrease the chances of tipping. Furthermore, wheel covers have been placed over the spokes to show that thought has been given to this important safety issue, but the full design could not be implemented due to lack of funds.

Evaluation

Testing of the prototype was performed on various mountain terrain which included rocks, stairs, ruts, tree roots, grades/ inclines, and corners. The carriage was pulled uphill, downhill, around corners, and traversed across uneven ground (where one wheel was above the other). The results from testing were very promising due to the high stability of the carriage. This stability was the result of the well placed center of gravity and the independent wheel motion, which allowed the seat to remain at a relatively constant height.

Turning was not a difficult task due to the relatively short drafting tube length, and the brakes worked exceptionally well (even when tested at a running pace on a loose-gravel road). The wheel covers were found to be essential for *anyone* riding in the carriage, as well as footrests to help brace the child from falling forward. Although qualitative in nature, the various adults which pulled the carriage stated that the carriage was surprisingly light to pull and that it felt like maybe 10-20 pounds on their back.

The weight of the carriage matched our expectations of a prototype, however future optimizing could eliminate more weight and make it even lighter to pull. Further optimization would also include manufacturing some parts in bulk which would decrease the cost and time to produce the hiking carriage. The carriage prototype was produced for less than $600 and is estimated to be marketed to the consumer for around $300.

The hiking carriage met the model family's expectations and beyond. The hiking carriage, once available to the consumer, will allow exercise for both the child (to learn to use some balance) and for the parent. Additionally, it gives a family the ability to spend quality time in the outdoors together, which may have a relaxing effect.

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DESIGN OF AN ERGONOMIC, DUAL-SURFACE MANUAL WHEELCHAIR PUSHRIM

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ABSTRACT

Two new manual wheelchair pushrims were created to improve the fit of the hand to the pushrim and to improve power transfer during propulsion. A concave trough and additional rim concentrically inside the standard rim were added to create a larger surface area for gripping. High friction vinyl coating was also added to the top and bottom portions of the rim while the outer side was left uncovered. These two modifications improve the fit of the hand to the pushrim and can improve power transfer to propel the wheelchair while decreasing direct trauma to the hands during use. A second larger version of the pushrim was also created to yield a better fit for people with large hands and quadriplegia. These new pushrims were designed to decrease potential for development of repetitive strain injuries such as carpal tunnel syndrome over time.

EXPLANATION OF PROBLEM

Identification

The number of people in the world relying on manual wheelchairs for primary mobility has grown significantly in the past few decades. It is a well-established fact that secondary injuries, such as carpal tunnel syndrome (CTS), are very prevalent in regular manual wheelchair users (MWUs). Many researchers have speculated that poor transfer of power to the wheelchair with standard pushrims and overuse of the upper extremities are to blame for the high prevalence. While several alternative propulsion devices have attempted to improve power transfer, few are well accepted for a number of different reasons. This suggests that there is still a need for a well-accepted propulsion-assist device for regular MWUs that can improve power transfer and possibly reduce the chances of developing secondary injuries such as CTS.

Review of Related Work

Many studies have been performed investigating wheelchair propulsion biomechanics and secondary upper extremity injuries. From several studies conducted in our laboratory, we have recently been able to relate CTS in MWUs to several propulsion biomechanical variables.(1,2) In addition, several studies on CTS in the unimpaired working population have found that long term exposure to high repetitious forces to the hand and wrist can cause CTS.(3) Since wheelchair propulsion is an everyday activity for MWUs, the problem of overuse cannot be directly addressed while using a manual wheelchair. Yet, changing propulsion technique, wheelchair setup, or the interface between the user and their wheelchair can modify the biomechanics that we found to be related to CTS.

Solution

Since propulsion technique and wheelchair setup are distinguished early in the rehabilitation process and rarely change over time, we felt redesigning the poor interface of standard pushrims would be the best way to address injurious propulsion biomechanics. A study by Gaines et al found that a group of MWUs preferred the use of contoured pushrims over standard rims in many common activities.(4) Thus, we felt a new pushrim should be reshaped for better power transfer, be simple and cheap to manufacture, be simple to attach to the wheelchair, and cause no changes in overall wheelchair dimensions. More importantly, this new pushrim would have to be well received in the MWU population, functional, and reduce the biomechanics that lead to secondary injuries.

METHODOLOGY BEHIND DESIGN

In terms of the wheelchair interface, we believed that the shape and size of standard pushrims was largely to blame for injurious biomechanics in transferring power to the wheelchair. In looking at standard pushrims, it becomes apparent that the tube diameter of these rims is too small to allow complete grip between the palm of the hand and the fingers. This reduces the contact area between the hand and the pushrim and increases the forces transmitted to the delicate structures of the hand. In addition, one's inability to grip the pushrim with the entire palm and fingers reduces mechanical efficiency by recruiting muscles for stabilization of the hand on the rim instead of delivering power to the wheelchair. Thus, the shape of the new pushrims was redesigned to eliminate these problems by offering a better fit between the hands and the wheelchair. Secondly, vinyl coating was added to the top and bottom of the rim to improve grip while the side remained smooth metal to allow breaking without causing trauma to the hands.

DESIGN DESCRIPTION

The shape and dual-surfaces of the new Small Ergonomic Pushrim are the two main components of this design that make it unique and a much improved interface for delivery of power to the wheelchair. The shape of the new pushrim includes the addition of a concave trough between the standard pushrim and the side of the wheel and an added rim concentrically inside the standard rim, as shown in Figure 1. These two components yield a gripping surface more contoured to the shape of the hand during propulsion, as shown in Figure 2. This is because the trough increases surface area around the thumb while the combined standard and inner rims yield a larger contact area for the palm while the fingers flex and grip the rim. The better fit and greater contact area stabilize the hand on the rim and allow more power to be transferred with the improved grip.

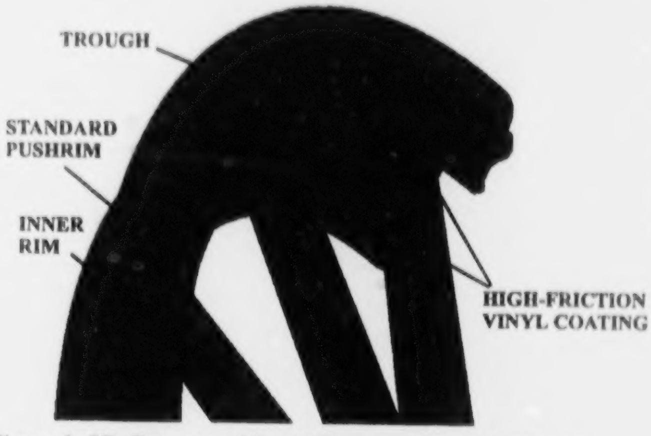

Figure 1: 3D-Cutaway of Small Ergonomic Pushrim Design

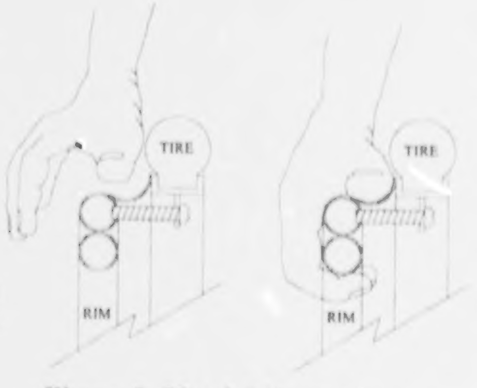

Figure 2: Hand Grip on New Small Ergonomic Pushrim

To further enhance power transfer, vinyl coating was added to the top and underside of the new rims as shown in Figure 1. The high-friction vinyl coating adds to the stabilization of the hand on the rim, which can improve power transfer and reduce hand slipping. Yet, the outside portion of the rim was not coated to leave a smooth, metallic breaking surface to prevent trauma to the hand caused by breaking on the high-friction surface.

Although the shape of the new pushrim was intended to contour under the hand, people with large hands and quadriplegia may not be able to take advantage of this new shape because the rim is too small. To address this, a second, larger pushrim of the same shape was developed. It is similar to the Small Ergonomic Pushrim, but the standard and inner rims have a larger tube diameter and the trough between the wheel and the rims is wider, as shown in Figure 3.

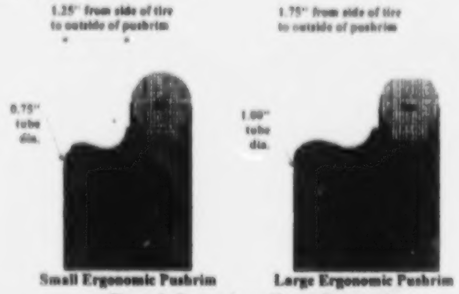
1.25" from side of tire to outside of pushrim
1.75" from side of tire to outside of pushrim
0.75" tube dia.
1.00" tube dia.
Small Ergonomic Pushrim
Large Ergonomic Pushrim

Figure 3: Comparison of Large Ergonomic Pushrim to Small Ergonomic Pushrim

MARKETABILITY

One of the key factors that makes this new pushrim marketable as an alternative propulsion assist device is that it can easily be placed on any manual wheelchair and presents very little change to the wheelchair aesthetics and accessibility. Moreover, individuals will benefit from an improved grip with the high-friction vinyl coating and contoured shape of the rim without the disadvantage of trauma to the hands during everyday use. Although redesigning wheelchair pushrims is not a new concept, one particular advantage of this new design is that it was easily manufactured and could easily be scaled up for mass production. Increased amount of material, time, and processes involved in manufacturing these new rims would make them slightly more expensive than standard rims, but overall manufacturing would simply be an expansion of the process and materials used to manufacture standard and vinyl coated rims.

VALIDATION OF DESIGN

While the new pushrims can offer a better fit to the hand and improved grip in the short term, the long-term goals of improving propulsion biomechanics will require further testing. Nonetheless, our laboratory has been studying propulsion biomechanics for years and will conduct future studies to measure differences in propulsion kinetics, kinematics, and power transfer between these new rims and standard rims.

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DESIGN PROCESS AND TEST RESULTS ACCORDING TO ISO STANDARDS OF A WHEELCHAIR BUILT OF PVC TUBING, PLYWOOD AND FASTENERS

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ABSTRACT

This study describes the design process as well as the results of tests on a manual wheelchair, designed using PVC tubing, plywood and fasteners and fabricated using readily available tools. The wheelchair was tested according to the ANSI/RESNA or ISO/DIS 7176-8 Wheelchairs: Part 8 Standard [3] Curb-drop and Double-drum test protocols for fatigue testing using a 100kg. ANSI/RESNA test dummy. The wheelchair prototype withstood both Double drum and Curb-drop tests without any permanent damage, deformation or failure that could effect its operability. This study demonstrates that a low cost PVC wheelchair can be designed to withstand the fatique and impact tests of the accepted wheelchair standards. It suggests that the design may be especially valuable to consumers in third world countries due to use of low cost materials and ready available tools and replaceability of parts.

BACKGROUND

In 1992, it was estimated that 1.4 million people use wheeled mobility in the US and that this number is still growing [1]. In the US most insurance companies will only pay for one wheelchair in a five-year period, whereas in third world countries, mobility products are often unavailable in rural areas, although the need for low cost mobility products is increasing. Consumers, clinicians, payers and manufacturers need quantitative test information to evaluate and compare wheelchairs.

In this study the fatigue life, durability and reliability for a low cost wheelchair build from PVC, Plywood and fasteners was tested using both the Double-drum and Curb-drop testing equipment according to the ISO/DIS 7176-08 Wheelchairs: Part 8 Standard [3].

RESEARCH QUESTION

Is it possible to design and construct a manual wheelchair using low cost materials (PVC tubing, Plywood and fasteners) and manufacture it using ready available tools? Will this low cost wheelchair comply with the industry standards, which many current quality wheelchair designs fail to accomplish? What design criteria make a wheelchair meet the requirements of the ISO/DIS standard?

METHOD: DESIGN PROCESS

The wheelchair prototype was developed using a limited amount of parts and materials listed in table 1. Table 2 lists the dimensions of the wheelchair prototype, which comply with the ADA requirements for accessibility [4]. Previous testing on current manufactured manual wheelchairs using the Double-drum and Curb-drop tester showed failure at the front caster frame junction and the side frame seat back rest junction [2].

Table 1: Used materials, components and tools to construct the wheelchair prototype

Part	Material	n	Dimension
Casters	Solid Rubber	2	Ø 8"
Wheels	St, Al, Rubber	2	Ø 24"
Rear axle	Steel tube	1	18xØ7/8"
T-connector	PVC	6	Ø 1"
90°-connector	PVC	4	Ø 1"
45°-connector	PVC	2	Ø 1"
Seat	Plywood		
Seat back	Plywood		
Caster housing	Plywood		
Wheel housing	Plywood		
Frame, 2 sides, back rest	PVC		
Stabilizers	PVC		
Footrest	PVC		

Tools
Portable hand drill
Floor mounted drill press
TIG welder
Cross cut hand saw
Hack saw
Adjustable wrenches
Open end wrenches
Hand pliers
"C" clamps

Table 2: Approximate dimensions of the prototype PVC and Plywood wheelchair

Total height	40in.
Width (no wheels)	19in.
Length (no wheels)	32in.
Total width	26in.
Total length	40in.
Wheel base	15.5in.
Weight	42 lb.

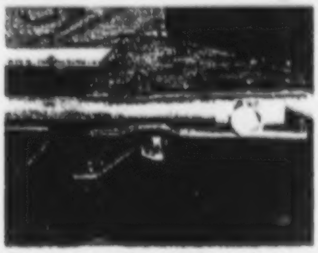
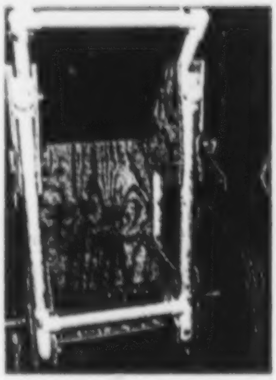


Figure 1: Caster housing



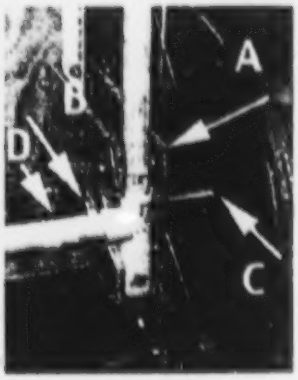
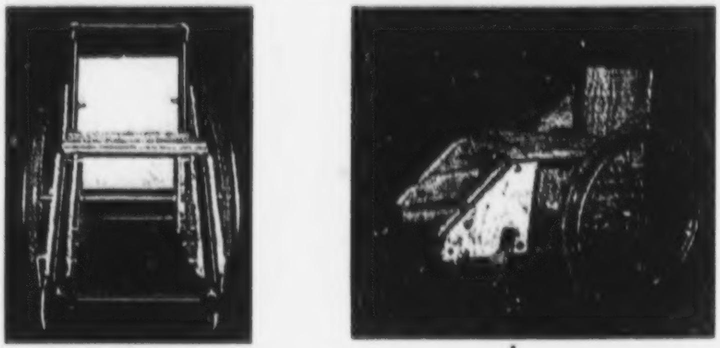


Figure 2 (left): Wheelchair frame shown from underneath
Figure 3 (right) A: two plates of plywood as wheel housing B: tightening nuts, C: Welded nut and wheel securement bolt, D: Steel axle tube

TEST SETUP

The used Double-drum tester consists of two rollers with 12 mm high slats attached to each. The front roller turns 7% faster than the rear to avoid exiting harmonics. The rear rollers turn at an equivalent speed of 1m/s. The wheelchair is balanced over the rollers with a swing-arm attached to the wheelchair's rear axles to provide stability. A single Double-drum cycle is defined as one revolution of the rear roller. The required number of cycles to meet ISO/DIS standards is 200,000, which means a run-time of approximately 56 hours. The Curb-drop tester is a device that lifts the wheelchair 5cm. and allows it to free-fall to a hard surface. The amount of cycles on the Curb Drop test is required to be 6666 which takes an approximated time of 9 hours to complete. Both Double-drum and Curb-drop tests represent an expected use from three to five years for the tested wheelchair. The ANSI/RESNA 100kg. test dummy used during the test, consists of solid steel blocks located in the shape of a human body. Torso weight as well as leg weight on the front of the wheelchair is acting on the wheelchair during testing on the Double-Drum and the Curb-Drop test apparatus.



a *b*

Figure 4a: Front-view, b: Isometric-view of PVC and Plywood prototype wheelchair

First the prototype wheelchair was tested on the Curb-drop tester, loaded with the 100kg test dummy. After passing this test the prototype wheelchair was tested on the Double-drum tester. Both tests were to be either tested to completion or stopped due to a class III failure, which is defined by the standard as permanent damage, deformation, or failure that significantly affects operability of the wheelchair.

RESULTS

The wheelchair prototype passed the required 6666 cycles on the Curb-drop tester and 200,000 cycles on the Double-drum without having any Class III failures. After 300 cycles on the Curb-drop tester one PVC joint was glued, which was overlooked during fabrication. One fastener was tightened after 1,463 cycles on the Curb-drop tester. After both tests the prototype wheelchair was removed from the test equipment and inspected for any sign of fatigue failure. There were no signs of failure or manufacturing discrepancies after both tests. A member of the design group used the wheelchair for approximately 15 minutes without any failures.

DISCUSSION

The PVC and Plywood wheelchair can be manufactured and replicated by a shop having basic mechanical abilities. The used parts and materials are relatively inexpensive and easy to manufacture. Overall weight of the wheelchair prototype (currently 42 lb.), which can be reduced by using less plywood and through making slots in the plywood plates of the back rest, and the front caster and rear wheel housings. Additional fatigue tests must be performed to assure maintained durability of the wheelchair. It is proposed that non experienced workers in developing countries could readily construct the wheelchair as it doesn't require high technical skills to build the wheelchair, when properly assembled it could result in a low cost, durable wheelchair to serve the needs of individuals requiring and relying on wheeled mobility.

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DESIGN OF A LOW-IMPACT WHEELCHAIR PUSHRIM

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ABSTRACT

Upper extremity pain and injury in manual wheelchair users are commonly attributed to high impact forces experienced during propulsion. A low-impact pushrim was designed to address the need to reduce the magnitude of these forces. The design allows the pushrim to rotate with respect to the wheel as well as to translate in the plane of the wheel when impacted by the hand during propulsion. The pushrim connects to the wheel by six pivoting extension spring mechanisms. Eight experienced wheelchair users evaluated the pushrim, using it to maneuver across a test course. Seven of the subjects perceived lower impact forces with the use of the new pushrim, and six subjects perceived the pushrim to return stored energy from the spring during the final stages of the push.

BACKGROUND

Upper extremity (UE) pain and injury are common among manual wheelchair users (MWUs). In a study of 239 MWUs, Sie et al. found that 64% of paraplegics and 55% of quadriplegics experienced UE pain (1). The most common sites of UE pain were at the shoulder and wrist. This pain limits UE strength and range of motion, decreasing mobility and functionality and thus resulting in loss of independence.

In a study relating wheelchair propulsion biomechanics to upper extremity pain and injury, Robertson et al. identified impact loading of the UE (which occurs as the hand first contacts the pushrim during the beginning of the drive phase) as the probable injury mechanism (2). They concluded that the rapid rise in force at the shoulder, particularly in the vertical direction, has a tendency to drive the humeral head into the acromial shelf. They also concluded that the rapid rise in force at the wrist occurs at a point in time when some individuals have a tendency to have a non-neutral wrist position. In support of these conclusions, Baldwin et al. found a relationship between the radial forces measured at the pushrim during propulsion and the incidence of wrist injury (3).

STATEMENT OF THE PROBLEM

Existing propulsion technology may be contributing to UE injuries. In a study by Burnham et al., the use of gloves with 0.25-inch padding in the palms to reduce UE injuries was investigated. The study found no significant difference in median nerve conduction due to propulsion with or without the gloves (4). Pushrims with a thick foam coating might be an effective solution, but when used without gloves, cause burning of the palms of the hands during braking and maneuvering. Therefore, a need exists for the development of an alternative pushrim, one that is designed specifically to absorb impact forces while maintaining the functionality of a standard pushrim.

DESIGN

Concept Generation & Evaluation

A wide variety of design solutions were investigated. In one design, rubber isolation shock mounts were used to replace the rigid plastic spacers between a riv-nut style pushrim and a tab-mount wheel. Evaluation of this design was promising, although the amount of flexibility was limited and almost undetected by the user. In another concept, the rigid spacers were replaced with extension springs. One end of the spring was attached to the pushrim and the other to the tab mount of the wheel. The attachment mechanism allowed the spring to pivot.. The pushrim was effectively suspended in place by the radially tensioned relationship between all of the springs. During use, when the hand impacted the pushrim, the springs in tension would expand, allowing the pushrim to displace and reduce the impact. During braking and turning, all of the springs were in compression and thus did not displace, allowing the equivalent responsiveness of a standard pushrim. Preliminary evaluation of this design showed it to be effective in reducing impact forces. It had the additional benefit of returning some of the energy stored in the springs during the later stages of the push phase. Its disadvantages included an inability to constrain the pushrim from displacing away from the user and a lack of a mechanical limit for the deflection of the springs. The lack of a mechanical limit allowed excessive pushrim displacement when climbing up steep grades.

Final Design

The final design built on the successes of the extension spring concept and addressed its drawbacks. Creating a mechanical limit was accomplished through the use of an existing design known as a safety extension spring, which is a compression spring with hooks passing through its center from opposing directions. When the hooks are pulled apart, the spring is compressed until it reaches full compression, at which time a mechanical limit is created.

Constraining the spring from lateral movement was achieved through the creation of an integrating shape to the safety extension spring mechanism. The final configuration, referred to as a single degree of freedom limited extension spring, is shown in Figure 1. The mating shapes are two aluminum rods, each with a long section that has been milled to half its diameter. The collars around the ends of the aluminum rod halves serve as the hooks in the safety extension spring mechanism. The full rod diameter is left in the pivot locations in order to maximize bearing strength and thus maintain a constant pushrim-to-wheel spacing.

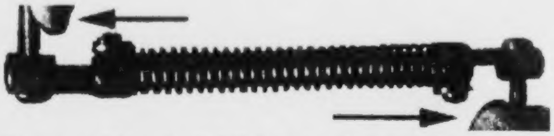

Figure 1. Single DOF Limited Extension Spring

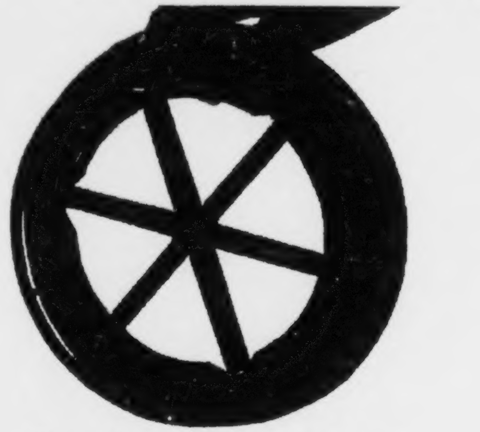

Figure 2. Low-Impact Pushrim

DEVELOPMENT

The initial prototype worked well. Displacement of the pushrim from the wheel was found to cause rubbing between the hand and the tire. This was addressed by the addition of a second pushrim mounted offset from the initial pushrim, which also allowed the pivot point of the spring to be relocated underneath the first pushrim. Additionally, a low friction, thin plate was added between the pushrim and wheel, thus allowing a smoother pushrim displacement motion. The final low-impact pushrim prototype is shown attached to a mag-style wheel in Figure 2. The pushrim displacement characteristics during propulsion revealed a general pivot point in the lower rear quadrant of the wheel, around which the entire pushrim would rotate upon impact. This behavior has been termed the "floating pivot."

EVALUATION

The design was evaluated by eight experienced wheelchair users. The subjects used the pushrims to maneuver their wheelchairs across a test course that included: a curved uphill path, a level sprint, a curved downhill path, a door threshold, a slalom course, carpet, a wheelie, and a standard ramp. Seven of the subjects perceived lower impact forces with use of the new pushrim and six of the subjects perceived the pushrim to return stored energy from the spring during the final stages of the push. One subject commented that he perceived a reduction in the amount of wrist abduction/adduction during the propulsion stroke. All of the subjects expressed a desire to evaluate the pushrim for a longer period of time during their everyday activities.

DISCUSSION

This design addressed the need for a low-impact pushrim. Subject evaluations demonstrated the pushrim's ability to reduce the impact forces perceived during propulsion. Despite this achievement, the design does have some disadvantages. The addition of a second pushrim, offset from the initial one, increases the overall width of the wheelchair, thus limiting mobility in space constrained areas. The design also adds weight to the wheelchair. Additionally, there is a concern that the design may result in reduced propulsion efficiency.

Future research needs to be conducted to determine the effects of this design on propulsion kinetics, kinematics, and efficiency. The development of an effective solution for the reduction of impact forces during propulsion will help reduce the likelihood of the development of UE pain and injuries in manual wheelchair users.

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INTERNATIONAL CUSHION DESIGN COMPETITION 1998

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ABSTRACT

The use of wheelchair cushions to help prevent the development of decubitus ulcers is well established in developed countries throughout the world. In developing countries the resources to purchase or manufacture state-of-the-art cushions is not available. In order to stimulate development of low cost, locally produced wheelchair cushions, a International cushion design competition was started in 1996 by the RESNA special interest group on International Appropriate Technology (SIG 17).

BACKGROUND

A variety of commercial wheelchair seat cushions are available in the United States. These seat cushions are designed to provide a comfortable, pressure-relieving area that is durable, easy to clean, easy to maintain, and lightweight. Many diverse technologies are used to achieve this, as one cushion is not ideal for all users, several different designs are necessary in order to meet the needs of each distinct wheelchair user.

STATEMENT OF THE PROBLEM

There are very few low-cost seat cushion designs for people with disabilities. Additionally, a large number of people in developing countries are in desperate need of assistive technology for mobility. Unfortunately, commercially available cushions are too expensive for people in developing countries or impoverished areas. The majority of commercial seat cushions cannot be produced in these areas because they require materials or manufacturing techniques that are not available. In result of this, pressure ulcers are the number one cause of death among people with disabilities in lesser developed countries.

RATIONALE

The purpose of the competition was to encourage the creation of inexpensive seat cushions for the prevention of pressure ulcers in people with disabilities living in developing countries or impoverished areas of the world.

DESIGN

Designs were required to be original; therefore, commercially available cushions were not eligible for the competition. In addition, previously submitted designs were not eligible. The design criteria required that the cushions be: low-cost, manufacturable in a developing country or impoverished area, aid in the prevention of pressure ulcers, not commercially available, comfortable, durable, low maintenance, lightweight

Contestants completed an entry form and submitted it with their cushion. The entry form was used to obtain more detailed information about the cushion, including:

- materials required
- quantities of each material
- source of each material
- estimated cost in U.S. dollars
- list of equipment/tools used to construct the cushion
- step-by-step, detailed instructions on how the cushion was constructed
- total construction time
- weight of cushion
- maintenance (cleaning and care)
- special features (e.g., adaptability of size and shape)

Judging occurred at the Annual RESNA Conference, June 1998 in Minneapolis, Minnesota. In 1998, a new component was added to the competition – the **People's Choice Award**. The cushions were set up in the Exhibit Hall and conference attendees were encouraged to sit on each cushion and then rank their top three choices in four different areas: 1) durability/maintenance, 2) stability, 3) comfort, and 4) overall performance. Over 100 people participated in this part of the competition.

DEVELOPMENT

In 1996, RESNA's Special Interest Group on International Appropriate Technology (SIG-17) developed and coordinated the first "Sore Butts" cushion design competition to stimulate ideas for pressure relief devices that could be manufactured in the required region and by the local population (1).The competition continued in subsequent years and the test procedures and methods used to judge and compare the design and performance of the cushions have improved over the years.

EVALUATION

Nine cushions were entered into the competition this year: six (6) from India, and one (1) each from Hong Kong, Pakistan and the US.

The cushions were judged by a team of experts that included rehab engineers, clinicians, and a consumer/designer. The cushions were evaluated in terms of their:

- comfort
- stability
- pressure distribution characteristics
- intuitive use
- catastrophic collapse
- wash-ability
- breathe-ability
- durability
- weight/portability
- cost of materials
- labor time

Judges were instructed to:

1. Briefly examine all of the cushions before beginning to score them.
2. Score cushions one at a time.
3. Place the cushion on a hard, flat surface and sit on it with feet properly supported.
4. Lean as far as possible forward, to the left and right.

5. Consider: ADL's, transfers, weight shifts, circulation, air exchange, easy drying, moisture wicking and temperature control.
6. Consider the questions for each category. Score the cushions using the -10 to +20 rating scale: -10 very poor, hazardous; -5 poor; 0 undecided/ neutral; 5 good; 10 very good; and 10 excellent.
7. Provide written comments for each cushion.

In addition, a new anatomical test fixture ("GelButt") was used to load each of the cushions consistently to make repeatable and comparable FSA pressure measurements.

DISCUSSION

Both the number of cushions and the quality of the cushion designs have improved each year since the first competition in 1996. The materials used and technologies employed in the design of the cushions shows that the competition is helping to stimulate thought and action toward the development of cushion fabrication programs in developing countries.

The competition also serves to help in the development of testing and evaluation materials and protocols here in the United States. Continuation of the competition will help improve the availability of cushions in developing and impoverished countries and could ultimately benefit a large number of people live a longer and more productive life.

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Service Delivery and Technology for Special Populations

PREPARING PERSONS WITH SEVERE DISABILITIES FOR COMPETITIVE MANUFACTURING EMPLOYMENT: AN ECONOMIC ANALYSIS

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ABSTRACT

Resources spent on training persons with severe disabilities for competitive manufacturing employment are shown in this paper to be a good investment both for the public and the persons receiving the training.

BACKGROUND

The Cerebral Palsy Research Foundation (CPRF), Wichita, KS, received a grant in 1997 from the U. S. Department of Labor's Displaced Worker Training Program to develop a program for individuals with severe disabilities. This program trained individuals on skills required for competitive manufacturing employment in the local Wichita economy.

The dominant type of manufacturing performed in Wichita and the surrounding area is the production of aircraft. Wichita is the home of the Raytheon, Cessna and Learjet aircraft companies as well as a large division of the Boeing Company. During the 1990's, the demand for aircraft worldwide has risen dramatically. Therefore, the demand for skilled laborers has also risen as the aircraft companies have increased their production levels. The local unemployment rate has been 2.3% and yet many persons with disabilities remained unemployed.

As technology levels have increased, the need for physical abilities to perform manufacturing functions has decreased. Instead, many current manufacturing functions require cognitive skills to interface with computer-controlled machines and processes. Therefore, the Department of Labor grant was utilized to explore the feasibility of training individuals with disabilities to perform manufacturing functions, which require more cognitive skills than physical skills.

OBJECTIVE

The objective of this paper is to analyze the economic impacts of training persons with severe physical disabilities for competitive manufacturing employment. The incentives/disincentives of this type of training program are explored from both the perspective of the government and the perspective of the individual participants.

METHOD

As part of the program set-up by CPRF, potential participants for the training program were screened and assessments were made to determine the knowledge and skills of each individual. After the participants were accepted into the training program, they each filled out a questionnaire concerning economic aspects of their lives prior to entering the program.

An economic model spreadsheet developed by the Wichita State University Rehabilitation Engineering Research Center (RERC) was utilized to analyze the data. This model was originally developed to help individuals with disabilities determine how employment will affect their overall economic situation.

RESULTS

Thus far, twenty individuals have completed the training and achieved full-time employment. There was considerable range in the work history of participants. Economic data was collected and compiled for eighteen participants.

Gender	
Male	**Female**
14	4

Age (years) *Mean=32*			
18-29	**30-39**	**40-49**	**50-59**
7	8	2	1

Type of Disability				
Cerebral Palsy	**Musculoskeletal**	**Sight/Hearing**	**Illness**	**Epilepsy**
5	5	3	3	2

Received SSDI/SSI/Medicare/Medicaid		
SSDI	**SSI**	**Medicare/Medicaid**
5	1	7

During the screening process conducted by CPRF, many of the potential participants were determined to not meet the previous employment criteria required for the Department of Labor grant. Thirty-five out of the 272 people interviewed were found to be eligible to enter the training program. Fifteen out of the thirty-five did not complete the program. Therefore, the program acceptance rate was 13% and the program completion rate was 57%. The average length of training time for the participants was five months and twenty days.

The following distribution shows the hourly wages of the training program participants. All of the participants received the minimum wage or higher.

Hourly Wages *[Mean=$5.99, Standard Deviation=$0.82]*				
$5.25-$5.49	**$5.50-$5.99**	**$6.00-$6.49**	**$6.50-$6.99**	**$7.00-$8.50**
6	4	5	1	2

The model, which was utilized to determine the economic impact of the training program, calculated the gross income and the net income after taxes for each participant. The after tax net income was calculated using estimated tax rates and the SSDI/SSI benefits the participant would receive based upon their current income. In most cases, the SSDI/SSI benefit went to zero since the participants had wages that exceeded the $500 substantial gainful activity (SGA) limit. The two participants who did not lose their SSDI benefits were blind. Therefore, their SGA limit was $1050. During the course of their training and employment, these two participants refused wage increases in order to keep their wages from exceeding the SGA limit.

Figure 1 illustrates the participant's estimated personal net income gain achieved by participating in the training program. These numbers are the cumulative totals for the next five years in today's dollars. The total estimated personal net income gain for all eighteen participants for the next five years is $696,864.

Figure 2 illustrates the state and federal governments' estimated net gain by sponsoring the training program. These numbers are the cumulative totals for the next five years in today's dollars and were derived by adding together the reduction in support benefits required and the income tax revenue generated. The total estimated government gain for the next five years is $478,807. The total government resources spent on training were $157,382

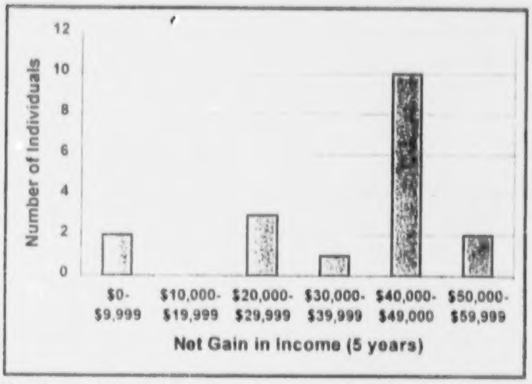

Figure 1. Increase in personal net income due to employment status. [Mean=$38,715, Standard Deviation=$15,405]

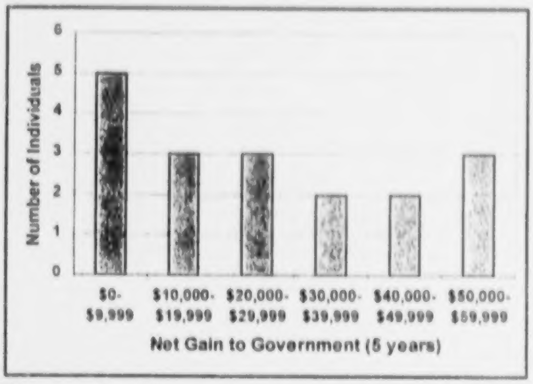

Figure 2. Net gain to State and Federal governments in support costs and increase in income tax due to employment status. [Mean=$26,000,Standard Deviation=$15,405]

DISCUSSION

The economic numbers reported in the results were developed utilizing several assumptions including the assumption that the individuals who completed the training program stay employed for at least five years. It was felt that five years was a reasonable planning period for the purposes of this study.

In all instances, both the government and the participants will potentially gain through their respective roles in the training program. The government will regain the resources spent on the training program in less than five years. All of the participants will realize economic gains by completing the training program and maintaining their employed status.

The data developed through this analysis represents one sample taken from the population of unemployed persons with disabilities. This economic analysis can serve as a basis for studies concerning training persons with severe disabilities for competitive manufacturing employment. It can also be utilized in discussions on the impact of re-training other segments of the labor workforce.

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ASSISTIVE LISTENING DEVICES PROGRAM

An Important Component of a Comprehensive AT Service Delivery Program

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ABSTRACT

Approximately 10% of the population experiences hearing loss. This percentage increases with older age groups, increasing the likelihood that older clients seen in AT clinics may have a significant communication impairment. To assess and satisfy the needs of this clientele, an Assistive Listening Device Program was established as part of a comprehensive AT service delivery program. This paper describes the requirements for establishing an Assistive Listening Device Program as well as the advantages and disadvantages of having such program as a component of a comprehensive AT service delivery program.

INTRODUCTION

Assistive Technology Service Delivery programs have flourished throughout the United States (1,2,3). Parallel to the proliferation of AT service delivery programs, there has been a significant increase in the commercial availability of assistive devices. The combination of these two factors has resulted in the establishing of assistive technology specific programs. These are programs that provide AT services focused on specific technologies. For example AT programs for wheelchairs, seating and mobility or programs for augmentative communication devices, computer access and environmental control units.

In contrast with the technology specific programs, there are comprehensive service delivery programs. According to Letechipia (4), a comprehensive service delivery program is a program that offers screening, evaluation, equipment procurement, training and follow-up in all of the following service delivery areas: positioning and mobility, augmentative and alternative communications, computer access and environmental controls; home, school and work site modifications; vehicle modifications and driver training; devices for visual impairments; devices for sensory impairments; orthotic devices, devices for recreation, and design of custom devices. Establishing a comprehensive service delivery program requires not only significant administrative support and commitment but also the availability of expert professional staff in each area of the AT.

One of the AT services commonly not included in the technology specific service delivery programs is the evaluation and recommendation of Assistive Listening Devices (ALD). Assistive Listening Devices are devices that enable deaf or hard of hearing individuals to maintain personal safety and communication ability for personal, large group, and entertainment purposes. Approximately 10% of the population experience a hearing loss. This percentage increases with older age groups, increasing the likelihood that older clients seen in AT clinics may have significant communication impairment. The purpose of this paper is to describe the requirements for establishing an Assistive Listening Device Program as well as the advantages and disadvantages of having such program as a component of a comprehensive AT service delivery program.

THE ASSISTIVE LISTENING DEVICES PROGRAM

The Assistive Listening Device Program was established as part of the comprehensive AT service delivery program at the Center for Assistive Technology (CAT). The CAT is a joint venture between the University of Pittsburgh Health System and the School of Health and Rehabilitation Sciences at the University of Pittsburgh.

To establish the Assistive Listening Device Program, clinical, technical, administrative and physical plant issues were considered. Clinically, it was required to recruit a certified audiologist with interest and experience in assistive listening devices and general knowledge in AT. Technically, the requirements included the acquisition of state-of-the-art evaluation equipment as well as a large sample of assistive listening devices. Administratively, the implementation of the Assistive Listening Device Program required establishing internal procedures, as well as separate billing and client records procedures. The physical plant required the installation of a soundproof booth, in addition to construction of space suited to house the audiology evaluation equipment as well as the assistive listening device collection.

Since its opening, the Assistive Listening Device Program makes available a variety of amplifying devices that can be used with hearing impaired clients seen at the clinic. Additionally, audiology services provided in the program include the evaluation and dispensing of assistive listening and alerting devices, including hearing aids. Clients' overall communication needs are assessed with the goal of integrating hearing aids, assistive listening technology, telephone technology, and alerting devices. The goal is the maximization of safety and functional communication abilities.

The staff includes a licensed audiologist, certified by the American Speech and Hearing Association. As with all assistive technology providers, it is incumbent upon the staff to remain current with new technologies.

Equipment required includes an appropriately calibrated audiometer, as well as a variety of loaner assistive listening devices. The devices available for client use include FM, infrared, and hardwired personal communication systems and alerting devices such as vibrating alarm clocks and smoke detectors. Telephone technology for deaf and hearing-impaired clients covers the breadth of devices from small portable amplifiers to TTY phones.

Presently 95% of clients are classified as self pay. The remaining 5% have insurance policies that partially cover the services provided by the Assistive Listening Device Program. Equipment is purchased via wholesale distributors, checked for proper calibration and functioning and delivered to the clients.

DISCUSSION

The Assistive Listening Device Program has been in operation for the last 15 months. The program services clients three days a week. During these 15 months, the program has provided services to 130 clients. Integrating the Assistive Listening Device Program to the AT services provided by CAT has resulted in numerous advantages for the clients. Clients receive comprehensive AT services in one location. Services are integrated and personalized. Prior to purchasing the devices, they can try a variety of them and select those that most appropriately satisfy their needs. Expert and non-biased advice on the features and limitations of each device assures that the selection is made to best suit the needs of each client. Another advantage for the client is that the recommendation of assistive listening devices is made taking into account the home, work or school environment.

When client needs for AT services go beyond assistive listening devices, a referral and evaluation can be made on-site. And, if other devices are required to increase the independence of the client, they will be recommended jointly, making the overall AT program personalized and integrated.

Administratively, the program has demanded the incorporation of audiologic procedure codes, client record documentation, and intense client interaction. Cash collection procedures also needed to be implemented. Processing assistive listening devices or hearing aid requests through traditional insurance plans has been time consuming.

The integration of the Assistive Listening Device Program as part of the AT services offered by the Center for Assistive Technology has been very positive. Integrating the new program has enhanced the quality and comprehensiveness of the services provided by CAT. The program has been very effective disseminating information to interested individuals regarding devices to assist with hearing impairments. The program has also disseminated information regarding other areas of the assistive technology spectrum.

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Analysis for Configuration of Screen Readers Using a State Machine Model

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ABSTRACT

A method of analysis and scripting for screen reading software has been developed which allows the screen reader to recognize specific screens of information and to rapidly access specific locations on each screen This method works best with information systems run from mainframe computers using terminal emulation software or MS-Windows database software with minimal graphics.

BACKGROUND

Screen reading software is used by blind workers to access personal computers by giving auditory feedback and reading information on the screen via a synthesized voice. The layout of application software varies widely depending on its purpose and the programming style of its author. Because of the wide variation between programs, a customized configuration usually must be created so that the screen reader will behave appropriately for the application program. The vendors of screen readers provide configuration files for the most commonly used software such as Microsoft Office, Lotus 1-2-3 Suite, and many other programs. The vendors do not provide configurations for applications such as a corporation's accounting systems, customer account information or database systems. Although screen readers will read the data from these applications, the layout of the screens is usually so dense that a blind worker has difficulty navigating the screen fast enough to perform tasks at a competitive rate.

STATEMENT OF THE PROBLEM

An accounting system must have a large number of data entry and report screens given the variety of functions that it must provide. The number of screens and their density of data make it very difficult for a blind user to learn the layout of the system and work productively. A rehabilitation engineer can compensate for this complexity by adding features to announce the display of new screens and dialog boxes, to provide timely access to important information through short cut keys and to announce important status changes such as error messages and screen prompts.

RATIONALE

Each screen usually has a title, ID number or a pattern of label locations which can uniquely identify it from other screens in the system Using this set of identifiers, a state machine model can be constructed of the application software. If the screen reader has an reasonably complete scripting language and a feature which can be used to monitor regions of the screen for changes, a state machine model can be used to program a complete set of orientation messages, custom short cut keys for each screen and automatically read error messages.

The AUTOSPEAK function in IBM Screenreader and IBM Screenreader/2 will monitor a screen area for a text string and execute a function if the string is appears. AUTOSPEAK functions are created to watch the locations of the identifier for each screen in the application. If the screen identifier appears, the AUTOSPEAK function is programmed to read the screen title, any other information the user needs immediately and to set a global variable for this screen. The value of the global variable is used in other reading functions as the control variable to read in the correct field locations for that screen.

Similar features exist in Jaws for Windows (JFW) 3.2. A JFW Frame is created at the location of each screen identifier and a script is written which runs when the Frame is activated by any changes within the area. When the script is activated, it will test for the presence of the unique identifier within the frame. If it is found, the global variable is set and the title and important fields are read aloud.

DESIGN

The first step in design of the screen reading modifications is to work with an experienced user of the system to learn the nature of the tasks performed, the software functions and screen layouts. It is helpful to print a sample of each screen and make notes about each field's meaning and importance. The sequence of data entry should be noted along with the sequence of review. Blind workers are usually entering data while talking to a customer on the telephone so it will be important for the user to be able to move through the entry and review in the proper sequence and in a timely manner.

The next step in designing the state machine model is to print another sample of each screen with a representative set of information in all fields. Then each field label and entry location is located using the screen reading cursor and the field location recorded. For DOS and OS/2 these locations will be in characters relative to the window. In JFW the locations are in pixels from the top and left of the window.

Analyze the screen layouts to find a text identifier unique to each screen. It is helpful if there is a screen ID code or title at the same location on each screen but not necessary. Scripts have been created with several dozen AUTOSPEAK or Frame locations without degrading performance. If one or more JFW 3.2 frames overlap, adjustment to the priority of execution will need to be made to keep the leftmost frame from masking the ones to its right. Priority is a property of the frame which can be modified with the JFW Frame Manager.

The last step and most difficult step is create a reading scheme that is logical to the user. Since there may be a number of screens each having twenty or more fields, the total number of fields in an application is too large to assign a single keystroke to each one fof voice review. Some type of strategy must be developed which creates a regular mapping that the user can remember. If fields are always reviewed in the same order, a single set of twenty to thirty function keys can be mapped in sequential order. Key "N" will read the Nth field on every screen. This should be in the order that the user needs to review the data rather than the order on the screen. If screens are organized in logical parts, a set of fields could be mapped to a single key with a pause (or wait for keystroke) between fields. Four or five such group keys per screen would give relatively rapid access to any field.

DEVELOPMENT

This method has been used to develop reading systems for two versions of a banking application for electronic wire transfer. The first system was developed using OS/2 Screenreader for the Moneynet system with a Tandem terminal emulator. As part of its Year 2000 process, the bank converted to the MTS funds transfer system using a Windows NT client and VT420 terminal emulator. JFW 3.2 was used for the screen reader in the conversion.

RESULTS

The OS/2 reading system for the Moneynet application was developed with approximately 200 man hours of analysis, programming, testing and training. It has been used by one blind employee for four year at SunTrust Bank. Productivity measurements show this user to rank first or second out of twelve in his department each month.

A JFW 3.0 reading system was created for the MTS software in parallel with the bank's conversion. The MTS software divided many of its screens into multiple sections and these panels could be scrolled independently. This caused the programming to take substantially longer, about 300 man hours for programming, testing and training. The two blind employees are using this version of the software and seem to be as efficient as with Moneynet but no productivity measurements have been provided by the bank as yet.

DISCUSSION

This is a time intensive method of programming screen readers but provides a system that is highly customized and efficient. It requires about two months to create this type of customization and to train the users. If the employer is able to plan that far in advance before the employee begins work, it is has been very effective.

We believe that a utility program could be created which would simplify much of the data gathering and could be used to create a state space model file which could be read directly by screen readers for more effective and precise reading of these types of screens. The screens would have to be static and not scrolling as in the MTS case.

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Fifth Annual Research Symposium

Medical, Functional and Psychosocial Consequences of Aging with a Disability: The Impact on Future Needs for Assistive Technology

METABOLIC CHANGES IN PERSONS AGING WITH SPINAL CORD INJURY

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ABSTRACT

Persons with spinal cord injury (SCI) have secondary medical disabilities that impair their ability to function. With paralysis, dramatic deleterious changes in body composition occur acutely with further adverse changes occurring with increasing duration of injury. Lean mass, composed of skeletal muscle and bone, is lost and relative adiposity is increased. The body composition changes may be further exacerbated by associated reductions in anabolic hormones, testosterone and growth hormone. Individuals with SCI have decreased levels of activity. These changes are associated with insulin resistance, disorders in carbohydrate and lipid metabolism, and probably premature cardiovascular disease. Although limited information is available, upper body exercise and functional electrical stimulation (FES) cycle ergometry of the lower extremities have been reported to have a salutary effect on these body composition and metabolic sequelae of paralysis. Perhaps other innovative, externally mediated forms of active exercise of the paralyzed extremities will result in an increased functional capacity, metabolic improvement, and reduction of atherosclerotic disease.

INTRODUCTION

Persons with spinal cord injury (SCI) have life-spans that are approaching those of the general population. As such, the diseases that occur in the elderly are becoming more prevalent in those with SCI. The adverse body composition changes and metabolic disorders that occur in individuals with SCI are not unlike those that are associated with advanced age. Persons with SCI lose lean body tissue, especially muscle below the level of paralysis, and have a relative increase in adiposity. Acute paralysis results in immediate muscle atrophy, but other factors, including hormonal, may also be operative over several years of immobilization to reduce muscle mass. Recently, a few reports have suggested that endogenous anabolic hormones, growth hormone and testosterone, may be depressed in persons with SCI. Metabolic rate falls, probably due to the loss of metabolically active lean body mass. The ability to perform aerobic exercise is reduced and dependent on the level and completeness of SCI. Thus, the determinants of insulin resistance, muscle, fat, and aerobic capacity, are negatively impacted by paralysis. Insulin resistance is associated with disorders of carbohydrate tolerance and lipid abnormalities. Glucose intolerance and diabetes mellitus have been reported to be increased in persons with SCI. Depression of serum high density lipoprotein (HDL) cholesterol, an independent risk factor for coronary artery disease (CAD), has been found in men with SCI. These metabolic sequelae as a result of paralysis form a cluster of risk factors for CAD. There are reports that suggest that cardiovascular disease occurs more frequently in persons with SCI.

REVIEW OF THE TOPICS

Body Composition Changes

Immobilization is associated with muscle atrophy. In persons with SCI, immediately after paralysis, there is a dramatic loss in skeletal muscle mass below the level of lesion. Because the paralysis is permanent, the muscle loss is not reversible. In addition, there is a rapid loss of bone in the extremities that are paralyzed, with higher cord damage resulting in osteopenia of both the upper and lower extremities and lower cord damage resulting in bone loss predominantly in the pelvis and lower extremities (1). However, recent evidence strongly suggests that both bone and muscle are continued to be lost in a linear fashion over decades after paralysis (2,3). Using an identical twin model, with one twin in each pair having a SCI, employing dual energy x-ray absorptiometry (DEXA), lean soft tissue was lost at a rate of about 3.9 kg every 5 years (2) and bone content was lost at a rate of 160 g every 5 years (3). Thus, sarcopenia is strongly associated with osteopenia in persons with SCI, as it appears to be in the elderly. Basal metabolic rate was reduced and strongly associated with the reduction in lean body tissue mass.

Disorders of Carbohydrate and Lipid Metabolism

A longitudinal study of carbohydrate metabolism in persons with SCI has not been performed to date. However, a few studies have found a greatly increased prevalence of disorders of carbohydrate metabolism in those with SCI (4-6). Duckworth et al. (4) reported that 27 of 45 subjects with SCI had an abnormality in oral glucose tolerance, with 23 being diabetic, approximately half of whom were insulin-resistant. Bauman et al. (5) studied 100 men with SCI and found 54% to have an abnormality in carbohydrate handling, with 22% diabetic; values for insulin sensitivity were linearly correlated with aerobic exercise capacity determined from a progressive maximal upper-body exercise stress test. Recently, studying 169 men and 32 women with SCI, Bauman et al. (6) demonstrated that individuals with the greatest levels of neurological deficit had the most adverse changes in oral glucose tolerance and higher serum insulin values compared to those with less debilitating injuries; higher peak serum glucose concentrations were associated with increased total percent fat.

A few reports have demonstrated that HDL cholesterol is lower in persons with SCI than in those who are able-bodied. Bauman et al. (7) found that almost 40% of the subjects with SCI had a serum HDL cholesterol level below 35 mg/dL, which is the cut-off value for being an independent risk factor for CAD; a strong inverse relationship was noted between serum HDL cholesterol and triglycerides. In a study of 541 subjects with SCI, a significant inverse relationship was found for the degree of neurological deficit and mean serum HDL cholesterol level, with the greater the deficit, the lower the serum HDL cholesterol level (8).

Depression of Anabolic Hormones

Several adverse changes of SCI may be exacerbated by reductions in anabolic hormones. Both growth hormone and testosterone have a beneficial effect on body composition to increase muscle mass and decrease fat mass. Growth hormone deficiency is associated with an increase in low density lipoprotein (LDL) cholesterol and a decrease in HDL cholesterol levels. In addition, these anabolic hormones have a beneficial effect on exercise performance. Aging has been shown to be associated with an insidious, gradual decline in these hormones.

Sixteen subjects with SCI were found to have a blunted growth hormone response to provocative stimulation compared with an able-bodied control group (9). Serum insulin-like growth factor (IGF-I), the "second messenger of growth hormone" predominantly synthesized in the liver and a measure of the integrated effect of growth hormone on the body, was found to be depressed in those with SCI (9). Other investigators have also noted a lower IGF-I in subjects with SCI. Twenty male subjects were demonstrated to have a lower mean serum testosterone level than that in controls (10); 9 of 20 subjects with SCI, but none of the controls, had levels of testosterone that were abnormally low. Of interest, a nonlinear relationship was found between serum free testosterone and IGF-I; serum free testosterone appears to plateau when serum IGF-I is equal to or greater than 250 ng/ml.

Exercise

Exercise has the potential to reverse some of the deleterious effects of SCI. However, the ability to exercise is dependent on the level and completeness of paralysis. Those with lower cord lesions have the use of their arms to exercise, whereas persons with cervical lesions have generally lost the ability to perform any meaningful physical aerobic activity. Loss of the ability to exercise the lower extremities prevents the major muscle groups in the body from being trained, and total exercise capacity is reduced.

In highly trained wheelchair athletes, the mean value for serum HDL cholesterol was closer to the normal range (11). In an effort to obtain some of the beneficial effects of exercise with the lower extremities, 12 subjects with SCI participated in a 12 week, 3 sessions per week, exercise training program of FES cycle ergometry (12). Thigh circumference and other measures of lean body tissue (e.g., body cell mass by total body potassium and lean tissue mass by DEXA) increased with a decrease in the percent of leg fat. Serum HDL cholesterol significantly increased.

Cardiovascular Disease

Persons with SCI have been reported to have an increased prevalence of premature cardiovascular disease (CVD). Epidemiological studies regarding those with SCI have revealed that age-adjusted mortality rates from CVD exceed that of the general population. Whiteneck et al. found that CVD was reported to appear prematurely and to be the most frequent cause of death in persons surviving more than 30 years after sustaining a SCI (13). A high occurrence of CAD, as determined by noninvasive nuclear medicine techniques, has been reported in those with SCI (14).

SUMMARY

Persons with SCI undergo changes in body composition, energy metabolism, anabolic hormones, and carbohydrate and lipid metabolism that are reminiscent of advancing age. Pharmacological intervention may treat some of these pathophysiological perturbations. A modality that stimulates atrophied skeletal muscle in as physiological a manner as possible may have a favorable impact on overall metabolism, reduce the atherosclerotic process, and perhaps afford the individual an improved quality of life and added sense of well-being.

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MEDICAL PROBLEMS IN PERSONS AGING WITH CEREBRAL PALSY

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ABSTRACT

110 Adults between the ages of 19-74 years with cerebral palsy were interviewed and examined. There were 52 subjects with dyskinesia, 28 with spastic quadraparesis, 11 with spastic diplegia and 10 with spastic hemiplegia. Neuromuscular dysfunction was mild in 2 cases, moderate in 72 and severe in 27. 76% of the subjects had multiple musculoskeletal problems. In 63% these occurred under the age of 50 years suggesting that abnormal bio-mechanical forces and immobility had lead to excessive physical stress and strain, overuse syndromes and possibly early joint degeneration. A number of patients had urinary complaints due to difficulties with toilet accessibility and likely neurogenic bladder. General healthcare seemed satisfactory for acute illnesses, but preventative healthcare was almost totally lacking. Treatment for the musculoskeletal system and availability of technology, seating systems and adaptive devices were essentially non-existent in stark contrast to children with cerebral palsy.

BACKGROUND

The United Cerebral Palsy Association estimates that there are approximately 400,000 adults with cerebral palsy in the United States. The number may be growing due to advances in medical care and the increased life expectancy of adults in general. Despite this, relatively little has been published regarding their general health and rehabilitation needs.

In the 1980's, Bax and colleagues reviewed the health needs of 104 young adults with physical disabilities living in the United Kingdom (1.) 45 had cerebral palsy. On the basis of medical examination and personal interview, the state of health of all subjects was judged to be poor. The majority of patients had serious medical and functional problems, not being attended to by organized health services. Bowel and bladder difficulties were found in almost 60%. Additional studies have also described organized healthcare for the adult with childhood onset disability as virtually non-existent, in contrast to the care provided for pediatric patients (3, 4, 5 & 6.)

OBJECTIVE

The objective of this study was to determine the general health and functional needs of a population of adults with cerebral palsy living in the San Francisco and Oakland California bay area between 1988-1990. It was the feeling of our research team that the availability of medical rehabilitation services for these adults was quite sparse, including a lack of technological intervention and adaptive equipment.

METHOD

110 adults with cerebral palsy between the ages of 19-74 were evaluated. All subjects were living in the community. Subjects were classified as having a mild, moderate or severe disability. Patients with near normal upper extremity function and ambulation with independence and self-cares were classified as having mild cerebral palsy. Patients with severe disability and maximal dependencies in all self cares and mobility's were classified as having severe cerebral palsy. The patients having more moderate cerebral palsy were individuals falling in between the definitions of mild and severe disability. There were 48 female and 53 male participants. A selection bias was felt present in addition to other factors created by the well known advantages of living in the San Francisco-Oakland, California area. All subjects were recruited with the help of United Cerebral Palsy of Alameda & Contracosta counties. A detailed medical history and physical examination with emphasis on the muscoloskeletal system was completed for all subjects.

RESULTS

General health problems of a serious nature were infrequent. One 54 year old man with dyskinesia experienced some anginal symptoms being followed by a general practice physician. A 74 year old female with spastic hemiplegia developed Parkinson's disease later in life. For the most part, acute illness was attended to by appropriate primary care physicians once the individual with cerebral palsy decided to access the healthcare office. The spectrum of general health problems identified in this population appeared similar to what one would expect to see in able bodied peers. One exception to this was bowel and bladder complaints, which were present in over 50% of individuals.

Approximately 30% of the subjects had history of fractures sometime in their life. Almost 30% of individuals reported dental problems. Over 60% of individuals with dyskinesia and approximately 25% of individuals with spastic quadriparesis had difficulty with drooling.

A major concern was the apparent lack of preventive medical care. Over 90% of the subjects did not have periodic general health evaluations. 90% of females were not having regular breast examinations, papanicolaou smears or pelvic examinations. Fewer than 10% of males were having a regular rectal examination for palpation of the prostate gland. Fewer than 10% of the subjects were being followed on a regular basis for cardiovascular risk factors such as hypertension, cholesterol, lipids or blood sugar. More than 90% of subjects over the age of 40 had not had an electrocardiograph in the recent past.

A number of conditions associated with cerebral palsy were identified. Hearing impairment was found in 10% and visual impairment in 25%. Approximately 20% had a history of seizures, with no individual being followed on a regular basis by a treating neurologist. Almost 20% of the population had severe disarthria, not understandable at a word level to strangers. Only 2 individuals had augmentative communication devices and these were outdated and with limited choices.

67% were using a wheelchair at the time of the study, the rest still ambulating either in the household or limited community. Only 3 individuals had an appropriate seating system as judged by the evaluation team. Almost all of the wheelchairs lacked an appropriate solid seating surface, postural supports and were frequently out grown with excessive wear and tear. Of the individuals ambulating, only 1 had an appropriate lower extremity orthoses. More than 90% of the crutches and canes examined were in disrepair and of inappropriate type or dimension. Individuals still ambulating at mid life were experiencing significant pain in weight bearing joints, enough to contemplate a more sedentary life style.

Musculoskeletal systems and complications were especially prevalent at an age under 50 years. Cervical pain was present in nearly 50% of individuals and in 75% of subjects with dyskinesia. Back pain was present in almost 50% of individuals under the age of 50. Scoliosis was identified in 58%, with lower extremity contractures in approximately 65%. 80% experienced significant muscle pain and spasm and almost 30% had pain in weight bearing joints. Most of the discomforts were felt to be bio-mechanical in origin and related to overuse type syndromes.

DISCUSSION

In general it seems that acute illnesses in these individuals were appropriately cared for. However, the absence of preventive medical care is of concern representing a stark contrast of age matched able bodied adults. In the vast majority of subjects, there was a complete lack of periodic general health and preventative evaluations. Some women had made attempts to obtain breast and pelvic examinations, but because of difficulties with inadequate examination room set-up, equipment and physical limitations resulting from the neuromuscular dysfunction, the examination was often stopped with a mutual consent of the patient and physician. Additional lack of preventative care was felt present with respect to dental health and treatment of drooling.

It was the research teams perspective that preventive medical cares are often lacking in a population of adults with cerebral palsy outside of this particular cohort. In addition, any attempt to provide preventive care to this population would have to include significant modifications in examination rooms, tables, equipment and consultation times. Greater sensitivity and more education of physicians and paraprofessionals is needed to allow optimal information gathering and access to comfortable examinations.

Bowel and bladder problems were often the result of environmental restrictions, with lack of access and/or personal assistance available to the patient. The likelihood of neurogenic bladder dysfunction was raised and probably was a factor in a sizable group of individuals with incontinence. Additional studies (7) have gone on to further address the likelihood of neurogenic bladder.

The essential total absence of technology and appropriate seating systems and adaptive equipment was striking. This was clearly in stark contrast to children with cerebral palsy and in the authors opinion, also adults with acquired physical disability later in life (multiple sclerosis, spinal cord injury and muscular dystrophy, etc.) Most non-ambulatory individuals with postural back pain experienced immediate relief simply by adding a lumbar roll or make shift adaptation to their seating surface.

The musculoskeletal symptoms and complications prior to the age of 50 in these individuals again was obvious. Most of the symptoms seemed to relate to excessive physical strain, biomechanical abnormalities and compensatory functional overuse. The high frequency of hip and knee pain and the appearance of such symptoms in most instances around 40 years of age suggest an early development of degenerative arthritis in weight bearing joints. Many individuals indicated that they would not walk much longer if the pain persisted or became worse. The incidents of fractures also seemed some what high raising the question of whether some degree of disuse osteoporosis might be a contributory factor in this population.

In the United States the complex medical needs of children with physical disabilities, including cerebral palsy, are provided under a parallel system of care. General preventive health care in the treatment of acute illnesses are the responsibility of pediatricians and family practice physicians. Specialized health professionals in care centers and schools attend to the management of the special needs related to physical disability. It appears that when these children live beyond the 18th year, they go on to experience a near total or total absence of specialty care services for their medical and rehabilitation needs. Service for acute illness appears available, but any preventive medical care again seems lacking. This lack of service to the adult with cerebral palsy would seem to put them at greater risk for medical and rehabilitation problems across the life span and for conditions more associated with the aging process.

It is hoped that further studies will be forthcoming regarding health and medical rehabilitation needs in adults with cerebral palsy and other conditions of childhood onset. At the least, the comprehensive professional services now received by children with cerebral palsy and other related conditions should continue across the life span.

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SECONDARY CONDITIONS EXPERIENCED BY PERSONS AGING WITH LONG-TERM PHYSICAL DISABILITIES

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ABSTRACT

Data from the Aging with Disability (AwD) Study are used to examine differences in the frequency of new health problems and functional limitations (i.e., secondary conditions) experienced by persons aging with the long-term effects of Polio (n=219), Rheumatoid Arthritis (n=187), and Stroke (n=151). Secondary conditions are operationalized as (1) the number of self-reported chronic health problems diagnosed or treated since the onset of the primary disability, and (2) decline in mobility status and use of personal assistance services since the previous reference period. Differences in secondary conditions are examined, first, within the AwD sample by impairment group and, then, between samples by comparing rates for the AwD study population to national estimates for same age-cohorts (45-64 and 65+) from the 1994-95 NHIS. Results reveal significant differences in the types of health problems experienced by persons aging with Polio, RA and Stroke, and document significant health disparities between disabled and non-disabled adults. Findings are discussed in terms of the importance of improving access to preventive services, ongoing rehabilitation, assistive technology, and consumer education.

BACKGROUND

The landscape of disability is changing dramatically in the United States (16, 14). For the first time in history, many individuals with significant disabilities, like their non-disabled counterparts before them, are surviving long enough to experience the rewards and challenges of "aging" (2, 3, 5). No where are the changing demographics of disability more evident than for persons *aging with* life-long and early-onset disabilities such as polio. Estimates from the National Health Interview Survey indicate that there are between 430,000 and 1,000,000 polio survivors alive today in the U.S., and more than half of these individuals are 55 years of age or older (1994, NHIS). Gains in longevity have also occurred for persons *aging into* disability for the first time in mid- to later life as a result of progressive diseases like rheumatoid arthritis (RA) and age-related conditions such as stroke (4,1). Adult-onset rheumatoid arthritis affects approximately 1% to 2% of Americans (National Institute for Arthritis, Musculoskeletal & Skin disease, NIAMS), causing chronic inflammation of joint linings, which leads to joint deformities and in some cases damage to internal organs. The good news is that considerable progress has been made in recent years controlling RA symptoms, restoring function, and slowing the progression of the disease itself (4). Similarly, in past ten years, life expectancy following a Stroke has improved from 3.5 to 7.5 years, and more than 20% of stroke survivors live at least 11 years beyond their first event (1).

The "bad news" is that in exchange for the benefits of increased life expectancy many survivors of long-term disability, as they age, experience the onset of new, and frequently unexpected, health problems and functional changes that threaten to erode their independence and reduce their quality of life (15, 12). Referred to in the public health literature as "secondary conditions," these new health problems have been variously defined to include *everything* from complications and injuries to new impairments, functional limitations, and changes in activity limitations (i.e., secondary disabilities) that are directly or indirectly related to the primary disability (11, 12, 9). The term has also been used to refer to new chronic diseases or comorbidities that affect the rest of the aging population, but may occur more frequently for persons with physical disabilities because of their narrow margin of "health" and the barriers they face in maintaining health (13, 6). Regardless of the definition being used, widespread agreement exists that secondary conditions constitute *negative* consequences of the disablement process which can be prevented or reduced with timely and appropriate interventions (9, 10, 8). Failure to respond *proactively* to the new health risks of secondary conditions can result in premature or "accelerated aging" and "excess" disabilities, which increase the personal and societal "costs" of disability (7).

RESEARCH QUESTIONS

This analysis seeks to address two questions related to the prevalence and distribution of secondary health conditions among persons aging with physical disability.

- Do individuals aging with different types of physical disabilities, acquired at different stages of the life cycle, differ in the *types* and *frequency* of secondary conditions they experience after the onset of their disability? And, if so, which impairment group reports the largest decline in function and the greatest "disease burden"?
- Is there evidence of "accelerated aging" among persons with disabilities? That is, do individuals with aging with physical disabilities, as a group, experience higher rates of selected health problems compared to age-matched cohorts from the population at large?

METHODS

Data come from the Aging with Disability (AwD) Survey Study, conducted between 1993 & 1998, under the auspices of the Rehabilitation Research and Training Center on Aging with Disability. The study utilized a cross-sectional, group comparison design, and all participants were randomly selected from two subject pools, a county rehabilitation hospital and a community pool, based on chronological age (<=60 vs. ≥61), gender or race/ethnicity (Hispanic, African-American or White), and age of onset or duration of disability. The achieved sample consists of 555 respondents: 218 for Polio, 186 for R.A., and 151 for Stroke. The average age of participants a time of measurement (T.O.M.) ranged from 58 for RA to 61 and 66 for Polio and Stroke, respectively. Age at initial onset of disability ranged from an average of 12 years for Polio to 39 years for RA and 61 for Stroke. The percentage of females was significantly greater for the RA sample (88%) than for either Polio or Stroke (56% and 34%, respectively), given the 3 to 1 sex ratio that exists for this condition. Moreover, both the RA and Stroke samples have a larger percentage of ethnic minorities, with 59% and 43% non-whites, compared to only 12% of the Polio group.

Secondary conditions are operationalized in terms of the onset of new chronic health problems and declines/change in mobility status and in use of personal assistance services (PAS). Chronic conditions consist of a total of 24 individual health problems, which include medical and physical complications of the primary disability, new onset of sensory impairments, and age-related diseases. Each condition was measured via self-report by asking respondents if they had been "diagnosed or treated for (insert name of condition) by a doctor or other health care provider since the onset of their disability." The specific health problems included were selected because they represent leading causes of mortality and/or additional sources of functional limitation (i.e., morbidity), and correspond to the chronic conditions measured by the 1994 National Health Interview Survey. Decline in mobility status was measured in terms of increased difficulty in community mobility and increased wheelchair use between T.O.M. and a previous period in the disability trajectory when respondents were at their "physical best" (applies primarily to Polio) or "one-to- five years ago" (applies primarily to Stroke & RA). Decline in personal assistance services was measured similarly in terms of an increase in use of PAS for instrumental activities of daily living (IADLs) between T.O.M. and reference period.

To test for "accelerated aging" the frequency of selected chronic health conditions reported by AwD participants was combined across impairment groups and then compared to national estimates for age-matched cohorts from the population at large based (NHIS, 1994). Comparable age groups were achieved between studies by dividing the AwD sample into the same two cohorts utilized by the NHIS: individuals 45 to 64 and those 65 and over. Respondents less than 45 years of age were omitted from this analysis. Differences in the frequency of secondary conditions were examined using tests of mean differences within analysis of variance (ANOVA) models, multiple comparison tests, and chi-square statistics.

RESULTS

The data analyzed indicate that the risks of aging with disability are not the same for persons living with the long-term effects of polio, rheumatoid arthritis, and stroke. In fact, significant differences among impairment groups are observed for 11 of the 14 conditions listed on Table 1. In most cases, differences in the frequency of individual health problems parallel group difference in chronological age, duration of disability and the underlying nature of the impairment. Respondents with the progressive disease of rheumatoid arthritis report more morbidity diagnoses (i.e., sensory and functional impairments), while those with long-term paralysis and mobility problems experience more causes of mortality. However, when all 24 chronic conditions included in the survey protocol are combined into an overall score, no within sample differences in the total number of health problems were observed. The average "disease burden" hovers around five conditions for all three impairment groups.

Table 1. AwD Sample Differences in the Frequency of Self-Reported Chronic Health Conditions

Selected Conditions	P Level *	POLIO (*n*=218)	R.A. (*n*=186)	STROKE (*n*=151)
Musculoskeletal Conditions				
1. Arthritis (Osteo)	≤.001	52%	61%	17%
Impairments				
2. Low Vision/Blind/Visual Neglect	≤.001	17%	28%	54%
3. Glaucoma	≤.10	5%	6%	11%
4. Hearing Loss	Ns	19%	25%	26%
5. Amputated Limb/Extremity	Ns	4%	2%	3%
Digestive Conditions				
6. Total G.I. Disorders *(i.e., ulcers, colitis, IBS, gastritis)*	≤.001	39%	43%	23%
Endocrine & Metabolic Conditions				
7. Thyroid Disorder	≤.10	14%	16%	7%
8. Diabetes	≤.01	11%	19%	23%
9. Kidney Disease	Ns	6%	9%	4%
Circulatory Conditions				
10. Heart Disease (includes MI)	≤.05	21%	13%	24%
11. High Blood Pressure	≤.001	47%	39%	73%
12. Stroke/Additional Stroke	≤.01	5%	4%	11%
Respiratory Conditions				
13. Asthma	≤.01	16%	15%	6%
14. COPD and/or Uses C-pap or Bi-Pap	≤.01	14%	10%	3%

* Corresponds to chi-square statistics for 2x3 contingency tables

Table 2 provides consistent and dramatic evidence of 'accelerated aging." Out of the 14 comparable conditions examined in both the AwD and NHIS studies, individuals with long-term physical disabilities report significantly higher rates for almost all mortality and morbidity diagnoses compared to their same-age cohorts in the population at large. In many cases, the magnitude of this disparity ranges from two- to ten times greater for the combined AwD samples than it is for estimates from the NHIS. Moreover, the pattern of accelerated aging exists for both age groups, although it is more pronounced for the youngest cohort of 45 to 64 year-oids, where only one exception was observed. Specific examples of "accelerated aging" occur for co-morbid conditions such as low vision/blindness, glaucoma, and asthma, as well as for several leading causes of mortality, such as diabetes, emphysema/C.O.P.D. and hypertension.

Table 2. Comparisons of the Frequency of Chronic Health Conditions between the Combined AwD Sample and National Estimates of Age-Matched Cohorts from the 1994 NHIS

	45 - 64 AGE GROUP			65 + AGE GROUP		
SELECTED CONDITIONS	Sample Diff [a]	AwD (*n*=302)	NHIS Estimate	Sample Diff. [a]	AwD (*n*=210)	NHIS Estimate
Musculoskeletal Disorders						
1 Arthritis (Osteo)	≤.001	42.9%	23.9%	≤.05	43.1%	50.2%
Impairments						
2 Low Vision/Blindness/Visual Neglect	≤.001	32.9%	4.5%	≤.001	31.0%	8.2%
3 Glaucoma	≤.001	5.9%	1.2%	≤.05	8.7%	5.4%
4 Hearing Loss	≤.10	17.1%	13.8%	Ns	33.2%	28.6%
5 Amputated Limb	≤.05	2.0%	.8%	≤.01	4.6%	1.8%
Digestive Disorders						
6 Ulcers	≤.001	12.8%	2.5%	≤.001	9.6%	3.2%
7 Gastritis	≤.001	5.6%	1.8%	Ns	3.6%	2.8%
8 Colitis	≤.05	2.6%	1.3%	≤.001	5.9%	1.4%
9 IBS/Spastic Colon	≤.001	7.6%	1.3%	≤.05	3.6%	1.6%
Endocrine Disorders						
10 Thyroid Disorder	≤.001	12.3%	3.0%	≤.001	12.3%	4.8%
11 Diabetes	≤.001	19.7%	6.3%	≤.05	14.1%	10.1%
12 Kidney Disease	≤.001	7.6%	1.7%	≤.10	4.1%	2.2%
Circulatory Disorders						
13 Heart Disease *(includes MI)*	Ns	13.1%	13.6%	Ns	27.8%	32.5%
4 High Blood Pressure	≤.001	51.6%	22.2%	≤.001	55.0%	36.4%
15 Stroke	≤.001	5.0%	1.8%	Ns	7.3%	5.7%
Respiratory Disorders						
16 Asthma	≤.001	14.1%	5.1%	≤.001	10.0%	5.1%
17 Emphysema/COPD (or Uses C-Pap/Bi-Pap	≤.001	10.2%	1.0%	≤.001	10.0%	4.6%

[a] P level corresponding to chi-square statistic for test of non-independence between samples.

The risks of experiencing new functional limitations also vary across impairment groups. Polio survivors are significantly more likely to have changed to a wheelchair and to report greater difficulty in community mobility since their period of "physical best" compared to their counterparts in the RA and Stroke samples. They are also more likely to have increased their reliance on personal assistance services for IADLs than are respondents aging with Stroke and RA. Moreover, unlike the pattern for polio, which is almost exclusively one of decline, a significant percentage of the RA and Stroke samples report improvement in functional status since their previous reference period.

DISCUSSION

Together, these findings identify significant differences in the profile of new health problems persons aging with Polio, Rheumatoid Arthritis and Stroke are at risk for, and document the health disparities experienced by persons aging with disability compared to the population at large. On a larger scale, they also provide insight into the changing health care needs of persons with long-term physical disabilities and the importance of revising our clinical priorities and age-based policies to reflect the changing demographics of disability. Specifically, our findings suggest that to reduce the risks of secondary conditions and "accelerated aging," persons with disabilities and their families need: (1) access to *more preventive and independent living services and at younger ages; (2) more informed medical and allied health providers* who are knowledgeable about the new health risks associated with aging with disability; (3) access to *rehabilitation services and specialists* on an ongoing, or as-needed basis, rather than limited to the post-acute phase of disablement; and, (4) *targeted health promotion programs* in accessible locations that incorporate training in self-care and self-advocacy, as well as education on assistive technology devices and services, and appropriate nutrition and fitness guidelines.

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FUNCTIONAL CHANGES IN PERSONS AGING WITH SCI

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ABSTRACT

Changes in general physical function, the effect of these changes on activities of daily living and needs for assistance were assessed in 150 individuals with spinal cord injury. The sample consisted of out-patients returning for follow-up at the spinal cord injury clinic at Rancho Los Amigos Medical Center in Los Angeles, CA. The average duration of injury of the sample was 13 years (range 1-37) and average age was 38 years (range 18-64). Twenty-four percent of those sampled experienced a decline or change in their physical function. The group experiencing declines was significantly older, averaging 45 years versus 36 years ($p<.0001$) and had a longer duration of injury, averaging 18 years versus 11 years ($p<.0001$) compared to the group reporting no declines. Of the problems experienced, fatigue was identified most frequently, followed by pain and weakness. Over half of the group with changes required additional assistance with activities such as bathing, transfers and dressing. Family members were identified as the primary helpers for both ADL's and IADL's and the increased need for assistance resulted in a greater reliance on family help in the group experiencing changes. Ninety-seven percent of those with changes reported a negative impact on their quality of life.

BACKGROUND

A person experiencing a spinal cord injury in early life now has a life expectancy approaching near normal ranges (National Spinal Cord Injury Statistical Center, 1995). The increasing longevity of this population contributes to the growing numbers of people aging with a disability. It is estimated that over 40% of all SCI survivors are now over the age of 45 (Berkowitz, 1993). Functional gains are expected in the early years post-injury, but recent studies have demonstrated that losses in function occur as people live with a spinal cord injury into middle and late life (Gerhart et al., 1993, Charlifue et al., 1998). The true nature and impact of these changes on a person's ability to carryout the once routine demands of activities of daily living, and ultimately the effect on the persons' life, are still being investigated. Certainly, some of the most important questions remain as to the underlying causes of these changes and thus how best to prevent or delay the onset of functional decline.

RESEARCH QUESTION

The purpose of this study was to investigate how aging with a spinal cord injury affects functional abilities for activities of daily living, instrumental activities of daily living, and needs for both technical and supportive assistance.

METHOD

A structured one-on-one interview was conducted with 150 people with spinal cord injury returning to the out-patient Comarr Spinal Cord Injury Clinic at Rancho Los Amigos Medical Center for routine follow-up appointments. The interview obtained information on basic demographics, current work and social roles, changes in physical function and ability to perform functional activities, satisfaction with current support and assistance, and changes in the use or need for assistive technology. The sample's average age was 38 years (range 18-64) and the onset of spinal cord injury averaged 25 years (range 1-58). The average duration of injury was 13 years (range 1-37).

A follow-up telephone interview was conducted with those persons who experienced changes in function to obtain additional information about the nature and impact of the physical decline. The time of onset of the physical or functional declines, the impact on the individual's quality of life, family and activities, the person's level of routine physical activity, and any unmet assistive technology needs were identified. Seventy-five percent of those experiencing changes were interviewed and partial information was obtained from the remaining twenty-five percent either from discussions with family member or chart reviews.

RESULTS

Of the 150 participants, twenty-four percent (n=36) identified that they had experienced a decline in their general physical function or ability to perform normal daily activities after having achieved a prior baseline of function post-acute SCI. The group that experienced change was significantly older than the group without a decline, averaging 45 years compared to 36 years of age respectively ($p<.001$). A comparison showed a statistically significant longer duration of injury for those with declines in function with average injury duration of 18 years versus 11 years in those with no changes ($p<.001$). Differences in the level of injury were not significant in the group with change, 46% had a cervical injury resulting in tetraplegia and 54% had a thoracic or lumbar level of injury causing paraplegia.

Fatigue, pain and weakness were the three most common problems identified by those with declines in function. Fifty percent of the group had fatigue. The fatigue was characterized by some as "an overwhelming sense of tiredness," feeling "completely worn-out," or "exhausted." Pain, the second most common problem, was identified by 36% of the group. The location and sources of pain varied, some described it as musculoskeletal in nature, while others characterized the pain as neurogenic. Thirty-one percent of the group described muscle weakness as a problem and this occurred primarily in the upper extremities. Other problems identified included pressure sores (22%), weight gain (17%) and a grouping musculoskeletal problems (36%) that included changes in spasticity, contractures or fractures.

Ninety-seven percent of the group with declines in function stated that their quality of life had been negatively affected or diminished by the changes. Almost two-thirds of the group reported that the changes had caused a decrease in their social activities. Over half had lost function to a point of requiring increased assistance with their daily activities. The activities of daily living (ADL's) that were affected the most and required additional assistance included bathing, transfers and dressing. The instrumental activities of daily living (IADL's) most frequently identified as requiring additional assistance were chores, shopping and meal preparation.

Family members were identified as the primary providers of assistance for IADL's in both the group with changes in function (55%), and those without a decline in function (60%). For ADL's, 42% of the group without changes were independent and 38% relied on family members for assistance. In contrast, 44% of the group with changes required assistance from family and 28 % relied on paid assistance and only 25 % were independent.

The use of assistive technology was evaluated in the total sample comparing the technology used at the time of discharge from acute rehabilitation with that used five years prior to the time of interview and with the technology used currently. An increase of use over time was found with slideboards, wrist hand orthoses, raised toilet seats, shower chairs, commodes, lifts, hand held showers and reachers. A decrease in the use of hospital beds and pill organizers was noted. The use of other technology items such as power and manual wheelchairs, leg orthosis, and seating systems remained fairly constant over time.

DISCUSSION

These data suggest that a collection of changes characterized by fatigue, pain, and weakness may create new functional problems in persons living into mid and late life with a spinal cord injury. These changes affected individual's quality of life and needs for both personal and technological assistance. The current age and duration of injury appear to be the critical factors in identifying who experiences these changes more so than the age of onset of the spinal cord injury or the level of injury. The exception to this was apparent in those acquiring a spinal cord injury later in life. The older an individual was at the time of injury, the sooner the changes or declines in function occurred. Prior findings by DeVivo and associates have reported a poorer prognosis for people in older age groups who sustained a spinal cord injury compared with their younger counterparts (DeVivo et al., 1990).

The changes in function discovered in this study occurred at an earlier age when compared to previous reports (Gerhart et al., 1993). The average age when this group began experiencing a decline was younger, 40 years for tetraplegia and 41 years for parapelgia, than reported by Gerhart and associates, 49 years for tetraplgia and 54 years for paraplegia. The study by Gerhart looked at the age when additional assistance was needed in individuals with a spinal cord injury greater than 20 years duration. This contrasts to this study that included people with shorter injury duration and asked for the onset of changes in general physical function rather than changes in need for assistance. The findings suggest that the actual physical decline may be recognized earlier than when the change in need for additional assistance emerges. In turn, when considering prevention, comprehensive physical assessments that attend to changes in physical performance may identify subtle declines at an early stage and provide an opportunity for effective intervention.

The personal assistance needs described in the total sample identified the important role family plays in meeting the caregiving needs of people with SCI. How the caregiving needs will be met in the future are a concern when considering that family members are also aging and face potential medical and functional changes themselves. Concern exists on a health care delivery systems level about access to assistance services that meet personal care and in-home assistance needs (DeJong et al. 1993).

The changing use of assistive technology evident in this study indicates an ongoing need for access to both evaluative rehabilitation services and for resources to acquire new technology throughout the life-span of those living with a spinal cord injury. Many managed care plans have not covered comprehensive rehabilitation services, personal care services or durable medical equipment or do so with severe restrictions (DeJong et al 1993). This potentially increases the risk of changing functional and technological needs to go unrecognized and therefore unaddressed, contributing to an increase in degree of handicap.

These findings suggest the need for ongoing access to comprehensive assessment services that address changes both on a physical and functional level as well as a technological and assistive support level. Additionally, continued investigation into underlying causes of the fatigue, pain and weakness and other common secondary conditions that lead to declining function will assist in focusing treatment efforts appropriately.

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THE IMPACT OF AGING ON THE NEED FOR JOB ACCOMMODATIONS

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ABSTRACT

Persons with disability were interviewed to determine whether functional declines associated with aging were affecting job performance and, if so, whether satisfactory job accommodations were being provided. Two groups were studied: 50 persons who were post-polio and 46 individuals with spinal cord injury (SCI). Individuals in the polio group had clearly experienced functional declines since they began working that were causing many new problems at work. Excessive fatigue was the principle cause of their problems. Twenty of the 50 interviewed had retired early because of their disability. The situation was very different for the SCI group. Though they had more work problems than the polio group, most of these problems would have been problems given the physical abilities they had when they first began working. The SCI group was more successful in obtaining accommodations, but the number of problems that were satisfactorily accommodated was low for both groups: 54.9% for the polio group and 69.3% for the SCI group.

INTRODUCTION

Reports of functional decline, coincident with aging, have been reported by persons with chronic disabilities. Two important questions, which have not been adequately addressed in the literature, is how these functional declines are affecting job performance and whether necessary accommodations are being provided to enable these individuals to carry out their essential job functions. The study reported here addressed these questions and had the following fundamental purposes:

1. Document the types of work problems being experienced by workers with a disability and determine whether the problems have gotten worse or have recently become problems as the persons have grown older.
2. Identify the types of accommodations being used to alleviate work problems and determine whether the accommodations are providing satisfactory solutions.

BACKGROUND

The initial onset for most survivors of paralytic polio occurred during the polio epidemics of the 1940s and 1950s. Though many were severely affected during the initial acute infection, the vast majority of patients regained some measure of neurological and functional recovery and were able to resume active, normal lifestyles. Thirty to 40 years after the initial onset of polio, many of the polio survivors began experiencing new health problems and functional changes that were related to the original disease [1,2]. The effects of these new health problems on job performance were also noted. In a survey of 539 polio survivors, Halstead and Rossi reported that a number of the respondents found it necessary to make major alterations in their lifestyles and even change their jobs to minimize new health problems [2]. Agre et al reviewed the medical charts of 79 post-polio patients and found that 36 patients (46%) acknowledged difficulties on the job because of new health problems [1].

Individuals with SCI are also experiencing health problems and physical symptoms that appear to be related to aging. The incidence of two of the most common medical problems, pressure sores and urinary tract infections, have been shown to increase with increasing age [3], while Lammertse and Yarkony reported that many persons with SCI experience an increased need for medical treatment 10-15 years after injury [4]. Pentland et al found that as persons with SCI age, they tend to be more fatigued, less active, and experience more symptoms and illnesses [5]. Gerhart et al interviewed 279 individuals in England who had a duration of SCI of at least 20 years [6]. Most (78%) reported that they required no more physical assistance than they had earlier in their injuries, however, 62 persons (22%) reported that they did. The average age when additional assistance was first needed was 49 years for subjects with tetraplegia or tetraparesis and 54 for those with paraplegia or paraparesis.

METHODOLOGY

Eligibility criteria for this study were 1) a history of poliomyelitis or SCI, 2) 30 years of age or older, 3) a work history of at least 5 years since onset of disability, and 4) currently working at least 20 hours a week for an employer or unemployed less than 5 years. Data was collected by telephone using structured personal interviews. The instrument used for the interviews contained five sections: demographics, employment history, functional assessment, work problems and accommodations. The interview generally took between 45 and 90 minutes.

A worksite evaluation and report were offered to participants who were working at the time of the interview. This was offered as a service to the participant -- to discuss problems that were not satisfactorily accommodated and to suggest accommodations that might be appropriate. Visiting the participant's worksite also gave us the opportunity to identify work problems that were not reported during the telephone interview.

RESULTS

A total of 96 individuals participated in this study: 50 who were post-polio and 46 with a spinal cord injury. The SCI group differed from the polio group in several important respects. They were younger (average age of 42.2 years compared with 53.6 years); they were far fewer years post-onset (19.8 versus 42.2 years); they were predominantly male (84.8%), while the polio group was pre-dominantly female (35% male); and they were better educated with 69.6% having attained a bachelors degree or greater compared with 46% of the polio group. Consistent with their younger age, the SCI group had worked less time overall (12.4 years compared with 26.0 years) and less time with their current or last employer (9.2 years versus 12.1 years). A very significant difference between the groups was that only one member of the SCI group had retired early because of their disability, whereas 20 (40%) of the polio group had done so.

Functionally, there were also important differences between the two groups. Most persons in both groups had ambulation limitations (100% of the SCI group and 82% of the polio group), but only one member of the polio group was nonambulatory compared with 91.3% of the SCI group.

Pain and/or fatigue were significant problems for some members of both groups, but the prevalence was lower in the SCI group. The SCI group reported only slightly more upper extremity limitations; 56.5% reported difficulty with reaching up, reaching out, grasping small objects, or carrying a heavy briefcase compared with 50% of the polio group.

One of the purposes of this study was to document whether the participants had experienced additional functional declines as they aged. When asked this question, 98% of the polio group stated that they had experienced functional declines later in life that started making a difference in their daily life; only 34.8% of the SCI group reported additional functional declines since their injury. Additionally, each participant was asked to rate the severity of their disability at the time of the interview and when they first began working after their disability. Most of the polio group (42 or 84%) reported that when they first began working, the severity of their disability was "slight or none." At the time of the interview, 37 of those 42 rated the severity of their disability greater than "slight." In all, 41 members of the polio group (82%) rated the severity of their disability at the time of the interview greater than it was when they first began working. The responses by the SCI group were very different. Only 5 (10.9%) rated their disability as ""slight or none" when they first began working; most (25 or 54.3%) rated their disability at that time as "severe" or "somewhat severe." Thirteen persons in the SCI group rated the severity of their disability at the time of the interview less than when they first began working. Only six rated it greater.

Each participant was asked to identify all of the problems that they had experienced on their current job (or last job if unemployed or retired) that were attributable to their disability. The polio group reported a total of 211 work problems. This computes to an average of 4.2 problems per participant. The total number of problems reported by the SCI group was 249, for an average of 5.4 problems per participant. In some cases (seven from each group), the participant's worksite was visited following the telephone interview. While touring the worksite and reviewing the participant's job functions, additional work problems were often identified. The average number of new problems identified at the worksite was 2.1 and 1.7 for the polio and SCI groups respectively. On the basis of this small sample, it is clear that the number of problems reported during the telephone interviews understates the actual number of problems being experienced.

The types of work problems experienced by the study participants are shown in Table 1. These data include the work problems identified during the worksite evaluations. Of the problems reported by the polio group, the largest number (68 or 30.1%) were classified as Access problems. Most of these problems resulted from the ambulation limitations reported by 41 (82%) of the participants. Most (60.2% in total) of the other problems were nearly equally divided between the categories of Performing Tasks, Using Equipment/Tools/Furniture, and Getting the Job Done. The majority of these problems were attributable to muscle weakness and the pain and fatigue experienced by most participants. For the SCI group, the greatest number of problems (101 or 38.7%) were in the category of Using Equipment/Tools/Furniture. Nearly a third of these problems (11.9% of all problems) had to do with their desk. Access was the second greatest problem area for the SCI group with 64 problems (24.5%). Fatigue and pain, while not as great a problem as it was for the polio group, was still a significant problem for the SCI group. Personal care problems were more common with the SCI group than with the polio group.

Table I. Types of problems experienced at work due to disability.

Types of Problems	Post-Polio		SCI	
	#	%	#	%
Access	68	30.1	64	24.5
Using equipment/furniture/tools	46	20.4	101	38.7
Getting the job done	50	22.1	31	11.9
Performing tasks	40	17.7	24	9.2
Personal Care	3	1.3	21	8.0
Transportation	12	5.3	17	6.5
Other	7	3.1	3	1.1
TOTAL	226	100%	261	100%

The possible affect of functional declines on the need for job accommodation was addressed in the following way. For each work problem that a participant had experienced on their current/last job, they were asked to imagine doing their job given the physical abilities they had when they first began working with their disability. Then they were asked "would the problem have been as much of a problem for you then as it is today, less of a problem, or not a problem for you at that time." As shown in Table II, the responses of the two groups were very different. The polio group reported that only 8.8% of their work problems would have been as much of a problem for them when they first began working; the vast majority of their problems would not have been a problem or would have been less of a problem given their physical abilities at the time they first began working. When asked what specific changes had occurred, they cited fatigue, pain and muscle weakness as the primary factors contributing to functional decline. With the SCI group, most (83.5%) of their work problems would have been as much of a problem when they first began working as they were when they were interviewed. In other words, few of their problems could be attributed to functional declines due to aging.

Table II. Problems caused by functional declines due to aging.

When you first started working, the problem would have been:	Post-Polio	SCI
as much of a problem as it is today.	8.8%	83.5%
less of a problem than it is today.	19.5	10.7
not a problem.	71.7	5.8

Of the 487 problems experienced by the 96 study participants, most were accommodated in some way. As shown in Table III, 69.9% of the problems experienced by the polio group were accommodated, while 85.4% of the problems reported by the SCI group were accommodated. For each problem that was accommodated, the participant was asked whether they were "generally satisfied with the solution to this problem." The percentages of problems with satisfactory accommodations are also shown in Table III; they are 54.9% and 69.3% for the polio and SCI groups respectively. Considering both groups together, about 3 of every 8 problems did not have a solution which the participant considered to be satisfactory.

Table III. Accommodations for work problems	Post-Polio	SCI
Problems Accommodated	69.9%	85.4%
Problems with Satisfactory Accommodation	54.9	69.3

DISCUSSION

Both the polio and SCI groups reported that they had experienced many problems on their current job (or last job if unemployed or retired) that were caused by their disability. The average number of work problems reported by polio participants was 4.2. SCI participants reported that they had experienced an average of 5.4 problems. Because these numbers are based on self-report, it could be assumed that they underestimated the problems experienced at work. In fact, when the authors visited the worksites of a subset of the participants interviewed, additional problems were identified: an average of 2.1 and 1.7 new problems for the polio and SCI groups respectively.

The primary cause of work problems for the polio group was fatigue. When asked whether fatigue interfered with any of their activities at work, 70% of the participants reported that it did. As shown in Table II, half (50%) of the group reported that they were still getting their job done, but they were extremely fatigued, especially later in the day. In many of these cases, the individuals were getting the job done only by putting in many additional hours. An additional 34% stated that their productivity had dropped off because of fatigue and/or pain.

One of the questions which this study addressed is are persons with disabilities experiencing functional declines as they age that affect job performance? The answer for persons who are post-polio is clearly "yes". Forty-nine of the 50 persons in the polio group (98%) stated that they had experienced additional functional declines since their original illness that made a difference in their daily life. In response to another question, 41 of the 50 stated that the severity of their disability was greater at the time of the interview than it was when they first began working. Finally, for each work problem identified, participants were asked whether the problem would still be a problem if they currently had the physical abilities that they had when they first began working. They reported that most (91.2%) of the problems would have been "not a problem" or "less of a problem" given the physical abilities they had when they first started working. Clearly, individuals in the polio group had experienced functional declines since they began working, and the decline in function had caused many new problems that affected their performance at work.

The situation was quite different for the SCI group. Only 34.8% of this group reported additional functional declines since their injury. In rating the severity of their disability at the time of the interview and when they first began working after their injury, only 6 of 46 rated it greater at the time of the interview. Most (27) said the severity was the same, while 13 judged the severity of their disability to be less at the time of the interview than when they began working. When asked whether their work problems would have been as much of a problem if they currently had the physical abilities they had when they first began working, only 16.5% of the work problems identified by persons with SCI would have been "not a problem" or "less of a problem" given the physical abilities that they had when they first began working. In summary, while a few of the SCI participants had experienced functional declines that were causing new problems at work, this was certainly not the case for the majority of the group.

While this finding was encouraging, a cautionary note must be sounded. The SCI group was a relatively young group; the average age of the group was 42.2 years compared with an average age of 53.6 years for the polio group. As stated previously, Gerhart et al found that of those persons with SCI that reported a greater need for physical assistance as they aged with their injury, the average age when additional assistance was required was 49 years for individuals with tetraplegia or tetraparesis and 54 years for those with paraplegia or paraparesis [6]. It would certainly be of great interest to repeat this study in 10 years to see whether the individuals interviewed will begin to experience additional work problems in coming years.

Many of the problems reported by study participants were not satisfactorily accommodated. Considering both groups together, 3 of every 8 problems did not have a satisfactory accommodation. In many cases, there was clearly an accommodation that would have helped the problem, but it had not been implemented because the employee had not requested the accommodation or the employer had refused. In other cases, no accommodation had been identified. This indicates a need for more information, directed at employers and employees, about the benefits of accommodations and the resources and services available to identify appropriate accommodations.

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EXPECTATIONS OF HEALTH, INDEPENDENCE AND QUALITY OF LIFE AMONG AGING SPINAL CORD INJURED ADULTS

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ABSTRACT

While our understanding of aging and mortality in spinal cord injury is evolving, precise estimates are still not available to assist people with spinal cord injuries to know what to expect as they grow older. This study showed that expectations of health are similar to those found in the general population, with about six years of poor health expected, presumably occurring at the end of life. Expectations of complete independence declined, but expectations of modified independence increased over time. Expectations of quality of life remained high until the fifth decade post-injury.

BACKGROUND

Through the recent work of a number of researchers, a clearer picture is emerging of the survival experience of people who have sustained a traumatic spinal cord injury. It appears that survival following spinal cord injury is increasing, although life expectancy is not yet at the level of the general population[1-3]. While these findings are encouraging, it is important also to understand the levels of health, independence and quality of life that accompany these additional years of life.

With regard to long-term health, Whiteneck and colleagues[3] found that 77% of their sample of long-term survivors of spinal cord injury reported that they were in good health. McColl and Rosenthal[4] also found 68% of a sample aged 45 years or older reporting good to excellent health. As regards independence, Whiteneck and colleagues[3] found 22% of their sample needing physical assistance with activities of daily living, and reporting handicap, or disadvantage resulting from disability. McColl, Rosenthal and Rowe[5] also found that a proportion of their sample described themselves as handicapped as a consequence of aging with a disability. The literature presents conflicting findings about quality of life with long-term spinal cord injury. Whiteneck and associates[3] found that quality of life and life satisfaction declined among spinal cord injured adults after the age of 50, and beyond 30 years after their injury. Eisenberg and Saltz[6] found that those between 45 and 54 and those with disabilities of durations greater than 20 years expressed the least satisfaction. Krause and Crewe[7] found that life satisfaction was greatest in those over 55, and those with a longer duration of disability. Zarb, Oliver & Silver[8] found that age and time since injury seemed to work in opposing directions, with those who were injured when older, and those at older ages being the least satisfied.

Health expectancy estimates have been widely used in the literature of the last decade to try to understand the relationship between population health and survival, both in the general population and in special populations. These methods allow us to estimate the proportion of remaining years of life that an individual may expect to spend in various conditions of health, independence and life satisfaction.

RESEARCH QUESTION

The study aims to calculate expectations of health, independence and quality of life in a population of aging spinal cord injured individuals.

METHOD

The study involved a retrospective cohort of individuals who had sustained a spinal cord injury between 1945 and 1990, survived at least one year beyond the injury, and received rehabilitation at Kingston General or Lyndhurst Hospital (Canada). In order to control for the known effects of age at injury, the cohort was restricted to those who experienced their injury at 25 to 34 years of age. Of 606 who met the inclusion criteria, 142 were deceased at the time of the study, and 286 were surveyed. Mortality information on the cohort was obtained through record linkage with the Canadian Mortality Data Base. Survey information on health, independence and quality of life was collected in telephone interviews by trained interviewers. Health was measured as self-rated perceived health on a ten-point scale. Independence was measured using the Functional Independence Measure[9]. Quality of life was measured using the Life Satisfaction Index[10]

RESULTS

Expectations of health: Over the five decades studied, expectations of poor health remained relatively stable, with a slight decrease, from 7 to 5 years from the first to the fifth decade post-injury. Looking at the proportion of remaining years of life, only those 40 or more years post-injury expected to spend more of their remaining years in poor health than in good health.

Expectations of independence: Expectations of complete independence declined over the five decades studied, with no one entering the fifth decade in a state of full independence. However, expectations of modified independence increased steadily, suggesting that individuals may have moved from full to modified independence over time. Expectations of dependence remained close to 20% of the remaining years of life. Different pictures emerge for those with paraplegia and those with quadriplegia.

Expectations of life satisfaction: Expectations of dissatisfaction with life remained relatively small over the whole survival period (between 5 and 8 years), and remarkably constant, especially over the last three decades. Proportionally, levels of satisfaction with life exceeded levels of dissatisfaction until the last decade, when individuals expected to spend 5 of their remaining years dissatisfied, and only 3 satisfied.

DISCUSSION

Expectations of health in the present study were similar to those found in the general population, including a period of about 6 years of poor health[2]. A closer look shows that the total expectation of poor health decreased from 7 to 5 years as the time since onset of injury increases from 0 to 40 years. This is probably accounted for in part by the "healthy survivor" phenomenon, where those who survive to the latter intervals are generally healthier throughout the lifespan. The more optimistic view of healthy life expectancy would suggest that the period of morbidity would be compressed into the last few years of life, thus increases in life expectancy could be attributed to increases in years of healthy life.

Expectations of independence following spinal cord injury suggest that there may be some homogenization of functional status after 30 years post-injury. While those who were previously independent seem to have moved to modified independence, those who began with modified independence do not seem necessarily to have become dependent. By stratifying the sample on the basis of injury severity (paraplegic vs. quadriplegic), a more detailed picture of changing independence emerges, with notably different patterns for different lesion levels.

The pattern of life satisfaction is consistent with that found by Whiteneck and colleagues[3] and Krause[11]. Life satisfaction appears to remain high for 30 years post-injury; however, it begins to decrease after 30 years post-injury or 50 years of age. Qualitative studies suggest that individuals with spinal cord injuries experience both an early onset and an accelerated rate of aging, in addition to anxiety about health, independence and institutionalization[4].

Similarities with the general population may be explained in terms of the "age-as-leveler" phenomenon: a situation where age acts to level differences found at earlier life stages between minority groups and the majority of the population[12]. This occurs because of the "leveling" impact of aging experiences that cross class, ethnic and disabiity boundaries. Previous research on perceptions of aging with a spinal cord injury has also given evidence of the "age-as-leveler" perspective[5].

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QUALITY OF LIFE INDICATORS AMONG PERSONS AGING WITH DISABILITY

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ABSTRACT

Quality of life (QOL) is a primary outcome in rehabilitation. QOL exists on a continuum, with distress and despair at the low end and life satisfaction at the high end. This study reports on measured depression and life satisfaction across four different impairment groups (post-polio, spinal cord injury, rheumatoid arthritis, and stroke) and a non-disabled group. Depression and life satisfaction were then correlated with measures of social support and health satisfaction, variables thought to influence these outcomes. Significant differences were observed across the groups on both depression and life satisfaction. Further, both health satisfaction and social support correlated significantly with depression and life satisfaction, but in opposite directions.

BACKGROUND

Maintaining a reasonable level of quality of life (QOL) after a disabling condition is one of the major goals of rehabilitation but one which is difficult to achieve because of a high incidence of health, economic and social problems. Definitions and measures of QOL vary, including those that are objective (such as employment status, income, home ownership) and those that are subjective (such as life satisfaction or psychological distress). Most rehabilitation experts subscribe to a subjective viewpoint (see Fuhrer, 1996, for example) because a) the person's own view is usually most valid, and b) subjective ratings reliably distinguish between individuals on other outcome criteria (health, functioning) while objective measures generally do not. QOL can be conceived of on a continuum, with high life satisfaction on one end and psychological distress on the other. Middle scores on this continuum reflect neither high nor low QOL.

This study assessed two indicators of QOL across four different impairment groups (spinal cord injury, post-polio, rheumatoid arthritis, and stroke) and one non-disabled group. Depression and life satisfaction were chosen because a) depression is the most important form of psychological distress relevant to persons with disability and, b) life satisfaction has been used in several other studies.

Interestingly, within impairment groups neither life satisfaction nor depression have been found to relate to severity of impairment (such as degree of paralysis) nor to extent of disability (such as inability to perform Activities of Daily Living) (Fuhrer, et al., 1992,; Dijkers, 1997). However, there is very little information about how depression and life satisfaction differ *across* impairment groups. Kemp and Krause (1999) compared persons with post-polio and person with spinal cord injury. On depression, persons with post-polio had lower mean scores and had fewer people above a cut-off score for major depression. They also scored higher on measures of life satisfaction than persons with SCI.

Previous research has shown that factors other than the severity of impairment or degree of disability are related to depression and life satisfaction. Two such variables are social support and health satisfaction. McColl and Rosenthal (1992) found that social support was highly related to depression in person with SCI. Numerous other studies (Friedland and McColl, 1987) have related social support to other measures of life satisfaction. Kemp and Krause (1999) found that life satisfaction related to health satisfaction in persons with SCI.

RESEARCH QUESTION

The objectives of this study were a) to assess how two indices of QOL, depression and life satisfaction, vary across different impairment groups, and b) to assess the relationship of these two indices to measures of social support and health satisfaction in each group.

METHOD

759 persons participated in this research, 211 with post-polio, 177 with SCI, 160 with rheumatoid arthritis, 151 with stroke and 60 in a non-disabled control group. The average age at time of measurement for each of the groups was 61.0 for post-polio, 40.1 for SCI, 66.1 for stroke, 58 for RA and 61.1 for the control group. Both male and female persons participated. Depression was measured with the Older Adult Health and Mood Questionnaire (Kemp and Adams, 1996), a 22-item clinically validated measure of depressive symptomatology. It also has cut-off scores for different levels of depression (normal, clinically significant symptoms and possible major depression). Life satisfaction was measured with an 11-item questionnaire which asks the respondent to rate different area of life (e.g., physical health, finances, family) on a 4-point scale (very satisfied, mostly satisfied, somewhat satisfied, mostly dissatisfied). Social support was measured by a modified form of the Interview Schedule for Social Interaction (Henderson, Duncan-Jones, Byrne and Scott, 1980). Health satisfaction was measured by that item on the life satisfaction scale.

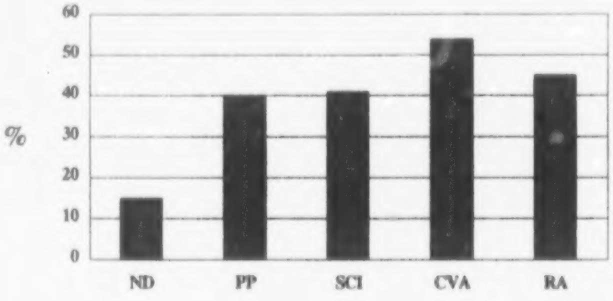
RESULTS

Data on depression were analyzed by computing both the mean score for each group and the percent in each group falling above the published score for any depressive disorder (≥ 5). The means (and standard deviations) were as follows: polio 5.8 (5.1); rheumatoid arthritis 7.0 (5.5); stroke 5.9 (4.3); SCI 7.2 (5.1) and non-disabled 3.2 (4.1). The Tukey test for mean differences indicated that all impairment groups were higher than the control group ($p < .001$) and that those with SCI or RA were higher than those with post-polio or stroke ($p < .01$). The percent in each group with a score above normal was analyzed by a 2x5 chi-squared (presence of depression x group). A x^2 of 25.6 $p < .01$ was obtained, indicating significant difference among the groups. The non-disabled group had significantly fewer depressed persons. See Figure 1.

Data on life satisfaction were computed by assessing the mean score for each of the 11 subscales and comparing them across groups by the Tukey test. In this analysis, the non-disabled group was higher than any impairment group ($p < .01$), and the post-polio and RA groups were higher than the other two ($p < .01$). See Figure 2. Finally, correlations were computed between depression scores, social support and health satisfaction and for life satisfaction, social support and health satisfaction. Across impairment groups, the average correlation between depression and social support was -.55 ($p < .01$) and with health satisfactino was -.31 ($p < .01$). The average correlation between life satisfaction and social support was .41 ($p < .01$) and with health satisfaction was .31 ($p < .01$).

The results for depression are depicted below in Figure 1, while Figure 2 shows the results for life satisfaction.

Figure 1: Percent with Elevated Depression Scores in Each Group



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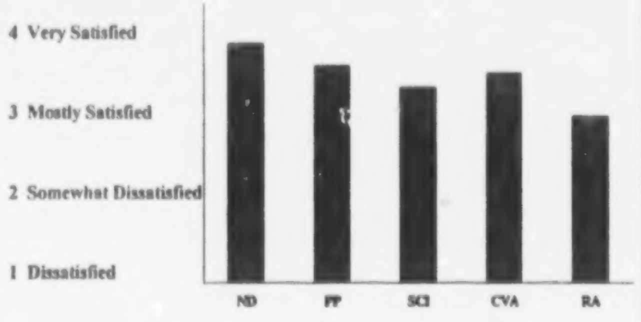

Figure 2: Average Life Satisfaction Scores in Each Group

DISCUSSION

Two measures of QOL were assessed in this study, both of which were significantly different between impairment groups and non-disabled comparison persons. Also, significant differences were obtained among impairment groups on both life satisfaction and depression.

The non-disabled individuals obtained average life satisfaction scores which placed them at a point between "mostly satisfied" and "very satisfied" with life, followed by person with post-polio, rheumatoid arthritis, spinal cord injury and stroke. The stroke sample was lowest, averaging a rating between "somewhat dissatisfied" and "mostly satisfied".

The results on depression were similar in terms of mean levels, with the non-disabled persons being lowest, followed by polio and stoke, and then rheumatoid arthritis and SCI. When analyzed by the percent having a possible depressive disorder, the results were even more dramatic. Whereas only 15% of non-disabled person had elevated depression scores, at least 40% of persons in each of the other groups did so. The highest group was the one with RA. These data strongly suggest that maintain QOL while living and agin with a disability is difficult.

Two mediating variables were related significantly to these outcomes: health satisfaction and social support. Both were strongly related to life satisfaction and to depression, but in opposite ways. While these results do not indicate causal mechanisms, they do point to two important considerations in maintaining QOL. All of the impairment groups obviously had seriously impacted health plus any additional secondary conditions which could make maintaining QOL difficult. Social support has already been well established as a buffer of stress and well being and its importance in QOL is maintained here.

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Paralyzed Veterans of America (PVA) Student Design Competition

1999 Paralyzed Veterans of America (PVA) Student Design Competition

The PVA Student Design Competition recognizes the exemplary work of students in the many disciplines comprising the field of Assistive Technology. This year, a total of 26 entries were submitted, many from students at schools not represented during previous competitions.

Designs were judged with respect to the following criteria:

* Appropriateness with respect to real user needs
* Input from intended users or manufacturers
* Innovation and creativity
* Manufacturability and market potential
* Cost to end-user
* Technical competence
* Documentation
* Working prototype or model

Award winners have made a special effort to bring their designs to the Conference. Please visit the Student Design Competition display, and see the talent and energy that will come to the field in the near future.

Many thanks are in order for the strong and consistent support provided by the Paralyzed Veterans of America (PVA). Through this support, PVA helps ensure that individuals with disabilities will have access to the cutting edge technology provided by skilled professionals. At PVA, Joan Napier is not only an advocate for the Student Design Competition, but an active part of the review and award process. Her work in this area was of great assistance and I look forward to her continued participation.

As with many other RESNA activities, Susan Leone provided much help, guiding the process along, keeping things on schedule, and providing advice when questions came up. Her efforts were much appreciated.

The difficult process of analyzing the designs was carried out with skill by an interdisciplinary panel, who generously devoted the time essential for a thorough and fair review. PVA and RESNA are indebted to them.

Finally, thanks must go out to all students who submitted entries. Although only five designs could be selected for the Award, the hard work put in by all students illustrates that the future of Assistive Technology is bright.

Glenn Hedman, MEng ATP
Chair, PVA Student Design Competition

MODIFICATION OF BOWLING RAMP TO INCREASE AUTONOMY AND NORMALIZATION

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ABSTRACT

Bowling is a popular recreational sport in America, yet those with profound disabilities are not easily included in this recreational activity. Current technology includes devices for those in wheelchairs who have upper body mobility and strength. Unfortunately, not all people in wheelchairs have the required mobility and strength to use this technology. The device presented in this paper allows people with limited strength and mobility to participate in this popular and exciting recreational activity. Such participation is achieved through the access of a remote switch, expanded positioning of the ball to the bowler, and an increase in ball speed which improves the cause effect relationship of releasing the ball and hitting the pins.

BACKGROUND

Rosedale School and Forest Services in Austin, Texas, teachers and recreational therapists of students with special abilities participate in many leisure activities, especially bowling. Bowling is one the favorite activities for the students and teachers. Bowling combines many beneficial activities: exposure to a stimulating environment, educating the community about the students, increasing cognitive skills at many levels, and it's fun!

While the Americans with Disabilities Act mandates accessibility for people with disabilities [1], inclusion for people with disabilities in recreational activities is not easily achieved. Although ADA requires public bowling alleys to have bowling ramps on the premises for people with disabilities, these ramps do not fit the needs of many disabled persons.

STATEMENT OF PROBLEM

Current technology is available to allow people with disabilities to participate in bowling. This technology is a basic ramp [figure1]. To use the ramp, bowlers in wheelchairs roll up to the ramp, place the ball on the rails in front of them, and push the ball down the ramp and down the lane. The ramp works well for those who have the ability to remain autonomous, whose standard wheel chair fit under the ramp, and who have upper body strength and mobility. Others, whose wheelchairs vary in size, who cannot lift or push a ball, or who are paralyzed, cannot use the ramp.

Figure 1

The goal of our project was to create a device that allowed users with profound disabilities to bowl autonomously, thus creating accessibility for everyone. We focused on solving issues that inhibit the ramp from creating an autonomous experience for the student and normalizing the game of bowling.

DEVELOPMENT OF DESIGN

Our first step in developing our device was to visit our customers at Rosedale School and Forest Services and join them while they bowled with the current ramp. We also interviewed the students' teachers, aides, recreational therapist, and physical therapist. By listening to our customers we were able to pinpoint and address major issues with the ramp. After identifying customer needs, the team analyzed the needs and specifications the new device should embody by following an established customer needs analysis [2]. A House of Quality was created to combine our customer needs and establish target specifications for our design.

Next, the design team visually brainstormed on concepts to solve the stated needs and problems with the current ramp. These concepts were evaluated, with particular attention to the following factors: accessibility by all, normal ball speed, switch-activated, low cost, easily manufactured. The design teams primary method of visually brainstorming was the 6-3-5 method, a stream-of-consciousness idea generator. From sessions using this method to induce creativity, three concepts were selected. Our team presented the final concepts to the customers for review, thus including them and their input in our decision making process. The three concepts were then evaluated using a decision matrix, to weigh the value of each concept and the feedback from the customer; the final concept was chosen and confirmed by the customers. Our customers were a valuable asset in the choice of our final design concept.

Proofs of concept prototypes were used for analysis of the design concept. Theoretical and experimental models further evaluated the prototypes. Friction models evaluated the motion of the ball while other calculations appraised the feasibility of the concept selected for the switch activation. From the testing and calculations, the design entered the alpha prototype stage.

DESIGN EMBODIMENT

The final concept was realized by creating a full-scale working alpha prototype. The importance of our alpha prototype cannot be understated. Several new issues were discovered in building and testing the alpha. The team sought to improve safety, optimize the speed of the ball, and decrease the amount of time between releasing the ball and hitting the pins--the cause/effect relationship. Because both Rosedale School and Forest Services have existing bowling ramps, the design team decided for cost and portability reasons that the new device would adapt to the current ramp. The device was presented to our customers and their feedback was encouraged and well received. Upon refining and re-testing our alpha, our team began building the beta prototype.

Figure 2

The beta prototype can be broken into two distinct assemblies: platform with switch-activation and drive mechanism. The platform addressed the problems of accessibility and switch-activation. The current ramp has only one position to place the ball; this was overcome by adding three distinct "divots" [figure 2] over a 30 inch span to hold the ball in place. The user is now able to approach the bowling device from many angles and orientations particular to his/her special needs. The divot hole size was optimized by minimizing the force required to push ball out of the divot. In the center divot [figure 2], a ½" plunger rises and falls via a slider-crank linkage attached to an AC geared motor. A slider-crank mechanism was implemented because of safety issues involved with the moving parts. By pressing a momentary switch, the plunger pushes the bowling ball out of the divot and down the ramp and returns below the surface for the next cycle. A key factor in this platform design is that it allows for both switch-activation and manual pushing without any reconfiguring the device.

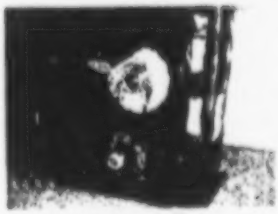
Figure 3

The drive mechanism is friction drive wheel powered by an AC motor that catches and spins the ball in a new novel way. Because intellectual property is being sought concerning this new friction drive for a bowling ball, a detail description of the mechanism cannot disclosed; however, in simple terms the friction wheel imparts energy to the ball, thereby increasing the velocity to a normal bowling speed. During the alpha and beta development, the adjustable parameters of the drive mechanism were tuned for a variety of bowling ball sizes and weights.

Learning from the previous prototypes and experience, the team manufactured the final beta prototype with emphasis on standard parts and off-the-shelf equipment. Because the team used readily available parts from a local hardware store, any further production will be less costly, as well as, easily reproduced by teachers or staff at Rosedale or Forest Services.

DISCUSSION AND CONCLUSION

After completing the beta prototype of the bowling device, the team presented the device to the customers at Rosedale School and Forest Services. The substantial improvement over the ramp was obvious and overwhelming. Our device decreased the time it takes the ball to strike the pins by a factor of two. In addition, the increase in accessibility was apparent when a student approached the device, faced the pins, and pressed the switch; in less than four seconds the pins fell.

People with disabilities are often excluded from recreational activities. Their need for recreation is seldom met because of issues of accessibility. Rosedale School in Austin, Texas and Forest Services of Austin, Texas are profoundly familiar with the need for technology for people with disabilities. Our project focused on improving bowling, a leisure activity that people with disabilities participate in. By expanding the positioning of the ball to the user, remote switch activation, and increasing the speed of the ball, our team design creates autonomy and normalization of bowling for children with special needs.

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PAMAID: A PASSIVE ROBOT FOR FRAIL VISUALLY IMPAIRED PEOPLE

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ABSTRACT

This paper discusses the design, development and evaluation of an intelligent mobility aid for frail, visually-impaired people. The device is based on the concept of a walker or rollator - a walking frame with wheels. The device, which is called the PAMAID (Personal Adaptive Mobility Aid) has two modes of operation – manual and assistive. In manual mode the device behaves very much like a normal walker. In assistive mode, the PAMAID assumes control of the steering and will navigate safely inside buildings, giving the user feedback on the immediate environment via a speech interface. It will also negotiate obstacles in its path. The PAMAID was evaluated in a nursing home in Ireland and the results of these tests will be briefly presented.

BACKGROUND

Comprehensive statistics on dual disabilities are rare. Some studies do provide compelling evidence that there is a substantial group of elderly people with both a visual-impairment and mobility difficulties. Ficke[1] estimated that of the 1.5 million people in nursing homes in the United States, 88% are over the age of 65 and 40% are over the age of 85. Of those 1.5 million people, 22.7% were visually impaired and 70.7% required some form of mobility assistance. The incidence of visual impairment increased with age, 14.3% of those aged between 65 and 74 had a visual-impairment and this rose to 30.8% among people aged 85 and over. The number of people affected by a mobility impairment also increased significantly with age from 60% in the 65-74 age group and 81.6% for those aged 85 and over. Rubin and Salive[2] report on a number of population based studies which also indicate a strong correlation between sensory impairment and physical disabilities.

PROBLEM STATEMENT

For those who have a mobility impairment in addition to a visual impairment, the use of standard navigation aids is difficult. Guide dogs are unsuitable, as they require that the user is relatively fit and does not need any physical support. A long cane cannot be used effectively as a navigation aid as well as a support aid, nor can a conventional walker be used simultaneously with a long cane. As a result, frail, visually impaired people can be very reliant on their carers to assist in their mobility. There is, however, a shortage of carers and their time and resources are limited. A full review of assistive technology for the blind is provided in [3]. It found that no devices existed that were specifically designed to increase the mobility of the frail visually-impaired.

DESIGN

The challenge was to build a mobility device that would give this potential user-group increased autonomy in an indoor environment. The device would have to be highly manoeuvrable and provide safe navigation through a partially structured environment (such as a nursing home or hospital) when required. The device would also have to provide the user with feedback on environmental features such that the user could localise themselves within their environment. The device should allow the user the choice as to whether the user or the device is in control. The compliance between the user and the device is of paramount importance. The user must feel comfortable using the device. It should be lightweight, easily transportable and require very little training on the part of the user. The user interface should be simple and intuitive and give the user efficient control of the device. It should also be easily adaptable to specific user needs.

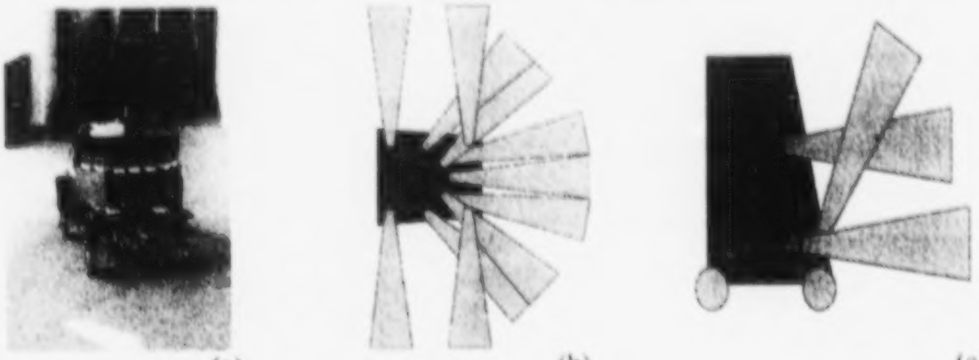
(a) (b) (c)

Fig 1. (a) PAMAID Device; (b) Sonar Configuration (Plan); (c) Sonar Configuration (Elevation).

DEVELOPMENT

The device being presented in this paper is the latest of four prototypes which have been built. The previous devices all had powered drive wheels. These devices would gently pull the users in the direction they desired. No matter how smooth the control over the drive motors, it was very difficult and expensive to get good compliance between the user and the machine. The latest device is pushed by the user. This means that there is very good compliance between the user and the machine. Thus, the device is more like a conventional walker, the key difference being that the castor wheels of a conventional walker have replaced by steerable wheels, which are controlled by an on-board computer. Much effort has been invested in the development of the user interface. A handlebar type interface has been the most successful. The user has very fine control over the device and very little training time is required. The PAMAID uses sonar sensors for navigation. The sensors were arranged to provide maximum coverage of the space around the user (see fig 1.). Sensors exist to protect the user from head-height obstacles and drop-offs. On-board obstacle-avoidance routines[4] mean that the user can walk with more confidence without worrying about bumping into potential hazards.

EVALUATION

The device has had one on-site evaluation to date with seven persons registered as visually impaired. They had a variety of additional physical problems such as arthritis, frailty, balance problems, nervousness and ill health generally. The users were all male with an average age of 82. Valuable information has also been gained from numerous on-site evaluations of previous PAMAID prototypes. The users found the device quite safe (4.4 out of 5 on a Likert scale). This was considered very promising considering that this was the devices' first evaluation. The users found it easy to remember how to use the device (4.2 out of 5) and were quite happy to move around with the device. They found the interface very intuitive and rated the machine as moderately to very useful for visually impaired persons generally (3.8 out of 5). Most of the users preferred to use the device in assistive mode. Some were worried about the overall weight of the device but this will decrease dramatically with further development.

DISCUSSION

The results from the first user evaluation have been very promising. The design was shown to be fundamentally good although further research will be necessary to improve its performance at more complicated tasks such as positioning users correctly so that they can sit down safely. The feature detection capabilities of the PAMAID are presently quite rudimentary but adequate for following corridors and recognising junctions etc. Future work will concentrate on improving and expanding the ability of the PAMAID to recognise important features in the user's environment. This will subsequently improve the PAMAID's repertoire of behaviours to include capabilities such as safe doorway passage.

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A Telephone Device to Improve Communication for Oral Deaf and Hard of Hearing People

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ABSTRACT

People who are oral deaf or hard of hearing have difficulties using voice carry over systems on the telephone because they can not distinguish the audio telephone signals like the dial tone and busy signal. Assistive listening device companies have over looked this difficulty. An assistive listening device has been designed to visually indicate the dial tone, busy signal, voices-on-line, line-in-use, and ringing signals on a standard telephone. Using the device, people who are oral deaf or hard of hearing can communicate more effectively over the telephone.

BACKGROUND

The Americans with Disabilities Act of 1990 mandates communication access for deaf and hard of hearing people. Access is normally provided through assistive listening devices [1]. Our goal was to provide an assistive listening device to increase effective communication over the telephone. Most people who are deaf or hard of hearing use a TDD telephone, a telecommunication display device. The TDD is a portable electronic machine with a visual display and/or printer used with a telephone that allows hearing impaired people to type and read conversations over the phone [1]. Approximately 20% of the deaf population, whose speech and language can be understood over the telephone, prefer to use a voice carry over system [2]. The system allows the user to convey their personality and feelings accurately over the phone. The oral deaf or hard of hearing person speaks normally into the phone, and reads the speech of the person they are talking to over an electronic display [1]. The main difficulty with the system is that it requires a conference call. It is difficult to place a conference call, if the status of the phone call can not be heard. We have a focus customer at the University of Texas at Austin that brought this difficulty to our attention.

LITERATURE REVIEW

Our design team conducted a thorough market survey of available assistive listening devices. We investigated and researched assistive listening device companies. The devices found did not meet our customer's needs. Devices were found that indicate a single phone tone, but not all of the needed phone tones. Marketed devices have not been developed that integrate all of the phone tones because of the technical difficulties and costs involved. Several of the phone signals overlap, which complicates the electronics.

STATEMENT OF PROBLEM

To increase effective communication over the telephone for oral deaf and hard of hearing people, a device is needed to indicate the different phone signals. Our team has designed and prototyped a telephone device that indicates the dial tone, busy signal, ringing, line-in-use signal, and voices-on-line on a telephone, while incorporating aesthetics and ergonomics.

DESIGN AND METHODOLOGY

A customer based product design methodology developed by Ulrich and Eppinger was used to design the telephone device [3]. Extensive customer interviews were conducted with audiologists, hard of hearing people and oral deaf people, in correlation with research on hard of hearing and deaf issues to clarify and refine the design task. The customer needs were interpreted into product engineering requirements through the House of Quality Method. The House of Quality illustrates the relationships between engineering requirements and customer needs, the relative importance of the requirements, and establishes target values for the engineering specifications.

The concept generation phase included multiple brainstorming sessions to encourage stream-of-consciousness techniques. Each functionality requirement of the product is brainstormed on and the results were combined and iterated into concept variants for the telephone device. The concept variants were then evaluated using the customer needs indicate telephone signals quickly and accurately while maintaining portability and aesthetics. The three highest scoring concepts were presented to the customer for feedback. The final concept variant, resulting from this process, was studied in further detail and then prototyped. Models of the electronic components, logic components, power supply, light display system, and device housing were all developed to investigate the concept variant.

DEVELOPMENT

After a thorough analysis of the design problem through theoretical and experimental models, we began the prototype stage of the design process. Alpha prototypes, i.e. physical models, were built to illustrate the functional feasibility and aesthetics of the telephone device. The electronic components were wired on a breadboard and tested on the telephone line to see if the circuit accurately indicated the telephone signals. The electronics consists of the following subassemblies: the power system, the light display system, the line interface circuit, the phone tone decoder circuit, and the logic circuitry. Our electronic design was unique because it decoded the signals using a tone decoder chip that did not require a microcontroller. The tone decoder circuit is state-of-the-art and was only released on the market in the summer of 1998. The electronic circuitry was the most challenging aspect of our device because the circuit had to be able to determine both the frequencies and the intensities of the frequencies to accurately determine the phone signals, while minimizing power consumption.

Foam models of the device housing were constructed to illustrate the aesthetics of the device, and were presented to customers for feedback. Acrylic plastic was then used for the housing because it is inexpensive, readily available in both sheet and tube form, and is available in a variety of colors. After experimentation with acrylic melting techniques, our team decided to CNC machine the acrylic.

Using the results of the alpha prototypes and customer feed back, our design team began working on our beta prototype. Our beta prototype was a comprehensive integration of the electronics and housing of our device (see Figure 1). The electronics used are all readily available so that the prototype can easily be reproduced. The form of the product is machined acrylic with brightly colored lenses including decals to indicate each phone signal quickly and accurately. There

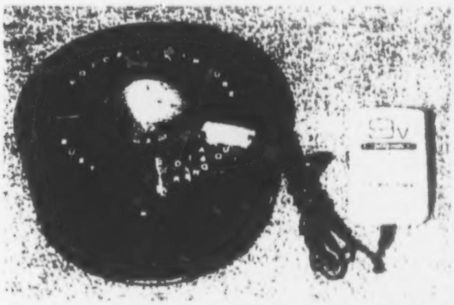

Figure 1: Telephone Device and Adapter

is an adapter to supply power with a built in rechargeable battery so that the device is portable. An on/off switch is provided to conserve power when the device is not in use. The consumer will only have to turn the device on and plug in the telephone jacks and adapter to use the product.

RESULTS AND BENEFITS

Our team prototyped a telephone device that indicates several telephone signals. The red light indicates a busy signal. The yellow light indicates the dial tone when the bulb is constant and the outgoing ringing (when the customer is dialing someone) when the bulb flashes. The green light indicates voices on-line. The light is helpful when a TDD is used because when the information is typed, it is hard to see pauses in the conversation. The consumer can avoid interrupting the other person on the phone with this feature, which can decrease miscommunications over the telephone. The blue light is useful when a telephone is shared with co-workers or family. It is on at any time when the phone line it is connected to is in use. This feature allows the consumer to realize when the phone is in use. The white light in the center of the device has a large flashing bulb that indicates an incoming ring. It grabs the attention of the consumer to indicate that someone is calling his or her phone line. All of the lenses are labeled with their appropriate signals for clarity.

We created a device to increase effective communication for oral deaf and hard of hearing people over the telephone. The telephone is one of the largest media for communication, so improving it increases the communication access available for oral deaf and hard of hearing people. We developed a state-of-the-art electronic circuit to distinguish phone tones, and professional device housing. We provided a service for our customers that the market was unable to provide.

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VOICE OPERATED WHEELCHAIR USING DIGITAL SIGNAL PROCESSING TECHNOLOGY

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ABSTRACT

A working prototype of a voice-operated wheelchair has been developed using commercially available Digital Signal Processing technology. The system provides a safe, economical, and compact solution to those people who are physically challenged and have limited options as to their means of local transportation. The device is small enough to hide under the seat of the wheelchair, consumes low battery power and can be converted to fit most existing motorized wheelchairs at a cost of less than $100.

BACKGROUND

The challenge of developing a voice- operated wheelchair has been an ongoing one. The development of a voice-operated wheelchair could be seen on any PBS station about 15 years ago. These were interesting designs but were unreliable and very expensive since they had to rely a personal computer on board the chair. The choices offered to a person with quadriplegia in today's society are much better thanks to the advancement of technology. The development of the Voice Operated Wheelchair using Digital Signal Processing (DSP) is a breakthrough in the sense that the device gives a wheelchair bound person an option that has not yet been available. Any physically challenged person with minimal speech capabilities is an ideal candidate for this DSP technology. The device requires neither a personal computer nor the need of any expensive components.

Dan Connolly of Foxboro, MA is one such person who can benefit from this device. Dan was in a diving accident 13 years ago and has been limited to a sip and puff wheelchair system. Dan has been our quadriplegic consultant on the design and has suggested to make the device operate as natural as possible. Dan comments, "I have been stigmatized enough already, if you can get the straw out of my mouth and allow me to use my voice instead, that would be great."

STATEMENT OF THE PROBLEM

The goal of the design was to develop a low cost, modular device that could be used on existing motorized wheelchairs. Other important considerations were to make the device extremely safe to operate and as natural as possible.

RATIONALE

The ability to design a low cost voice-operated wheelchair was made possible by the advent of DSP technology. Utilizing DSP also enabled the device to be very small which has been a problem with past systems since they needed to house a personal computer. The device would also suit more users if it were made modular so as to plug into as many existing motorized wheelchairs as possible. This device was designed around a Quickie P300 motorized wheelchair that was equipped for a joystick. At the completion of the design, the joystick was unplugged from its controller box and the voice-control device was simply plugged in.

DESIGN

A description of the voice-operated system is one of natural control using voice commands to navigate ones wheelchair in any circumstance, with all of the safety that currently exists on today's high tech wheelchairs. The considerations for this design were to have the system to be as failsafe as possible while keeping it modular and economical. Redundant voice commands are the key to the successful failsafe system as well as a mechanical switch which is installed in the head area (the head area is the only area that will be specific to the individual user). The idea of keeping the unit as modular as possible is directly related to cost. By keeping the unit as "plug and train" as possible the device can be easily produced for many users and can also be trained easily by the user, along with a little help from a friend who can follow simple setup instructions (less complicated than programming your average VCR). A large portion of the economical benefit from this design comes from the fact that this unit does not require an onboard personal computer, the unit is self-contained. The limiting factor with this design approach is with the number of different motor controllers on today's wheelchairs, but the unit can be modified to adjust to most motor controllers.

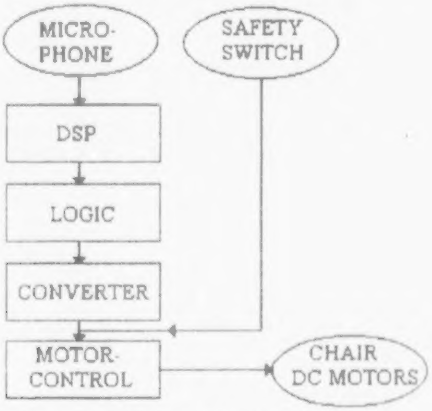

FIGURE 1: DSP driven voice operated system design layout

DEVELOPMENT

The voice-operated system consists of four main components. The heart of the system is the digital signal processing circuit. Supporting the DSP is the programmable logic circuit, the converter circuit and the mechanical safety switch circuit. The signal processing circuitry consists of a commercially available DSP chip, which receives verbal commands from the user with the aid of a simple microphone, see figure 1. The first phase of redundancy is encountered here so as to help avoid undesirable responses from the system and the surrounding environment. The verbal commands are outputted from the DSP chip in the form of an eight-bit word, which are then taken by the logic circuit and analyzed. Part of the logic circuitry is a commercially available PIC chip which processes the eight bit input and makes a decision based on that information. Once again, redundancy is encountered in the device. The decision is then further processed into the next circuit that takes the digital input and converts it into the necessary analog output which is needed to produce the desired response from the motor controller, such as moving the wheelchair in the forward direction. The final section of circuitry is the mechanical switch that overrides all of the aforementioned circuitry. This circuit acts as the surefire failsafe in the line of defense against erroneously entered commands.

EVALUATION OF DESIGN

The first running of the prototype showed very promising results. The device responded nearly 100% accurate in low and moderate noise environments. Problems did arise however, in a high noise environment. Even though the communication problems existed in the high noise environment, the systems failsafe shutdown due to extraneous noises proved to be 100% accurate. A note on the versatility of the device; an Arabic speaking classmate of mine trained the system to his native language within minutes. The system response to his training in a moderately noisy environment was 100% accurate.

DISCUSION

Many of the motorized wheelchairs available today can be easily converted into a DSP driven voice operated wheelchair using a device as the one just described. Having this option opens up a whole new world of possibilities for a person who has previously been limited to sip and puff technology. In previous versions of the voice-controlled wheelchair a computer was required to process the data, increasing the overall cost of the device to well over a thousand dollars. The design of this plug-in module, which takes advantage of the existing motor controllers, costs less than one hundred dollars to produce. Thus, the cost alone makes the device available to many more users who have been unreachable in the past due to the high cost of such technology.

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A WHEELCHAIR-BASED MOUNTING SYSTEM FOR AUTOMATED POSITIONING OF AN ELECTRONIC AUGMENTATIVE COMMUNICATION DEVICE

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ABSTRACT

This paper describes a powered mounting system for communication devices that is designed for the powered wheel-chair environment. A spherical linkage mount allows a single actuator to maneuver a communication device from a horizontal position in the lap of the user to a vertical position at the side of the wheelchair. Research in the design of spatial linkages is yielding new devices with unique capabilities for mechanized movement. The efficient design and construction of singly-actuated spatial movement, tailored to specific needs, can provide a cost-effective opportunity for independent activity that is fundamental to the development of autonomy.

BACKGROUND

It is has been shown that assistive technology provides functional benefits for adults with cerebral palsy, with and without retardation (1). In addition, positive psychosocial impact of assistive technology has been reported on the quality of life for clients with Amyotropic Lateral Sclerosis (2). This work suggests that wheelchair mounted devices that can provide more control of the immediate environment and decrease dependence on care-givers may enhance feelings of competence, self-efficacy, self-confidence and self-esteem.

This paper describes an actuated mounting system that provides deployment and stowage of a lap-based communication device at the command of a head switch. This work is the result of collaboration between researchers of the Robotics and Automation Laboratory (University of California, Irvine) and the Center for Applied Rehabilitation Technology, Rancho Los Amigos Medical Center; Downey, CA.

STATEMENT OF THE PROBLEM

Clients of the Center for Applied at CART who use powered wheelchairs often also use electronic augmentative communication devices. Efficient use of these systems usually requires that this device be mounted to the wheelchair and positioned in the lap of the user. Current mountings are stationary and require care-giver intervention to reposition the device for any reason. The UCI spherical linkage mount provides a simple mechanized movement that is the repeatable and reliable for stowing and deploying a communication device at the command of its user. The result is an increase in local control of their environment.

METHOD

Several issues were critical to the development of a practical design. The mounting system had to be compact and compatible with various powered wheel-chair systems. Its operation had to be smooth and reliable with a simple user interface. A spherical 4*R* linkage, consisting of four bars connected by hinged joints, dimensioned to provide a spatial reorientation is the centerpiece of the new mounting system. This linkage requires only one actuator to guide the communication device from a horizontal position in the lap of the client to a horizontal position beside the wheelchair.

The design of spherical 4R linkages requires a graphical software tool ***SphinxPC*** developed by researchers at the UCI Robotics and Automation Laboratory (3). ***SphinxPC*** allows the designer specify precision locations for the communication device and compute link dimensions, and location of joint axes, joint angles, that defining the required motion. See Figure 1. This software allowed us to develop the kinematic skeleton that prescribes the movement of the mounting system.

The kinematic skeleton must be transformed into physical links and rotary joints that support the load of the communication device and do not collide during their movement. Figure 2 shows the solid model of the final physical prototype. This model was used to drive CNC machining tools to manufacture the mounting linkage's aluminum links and hardened steel axles.

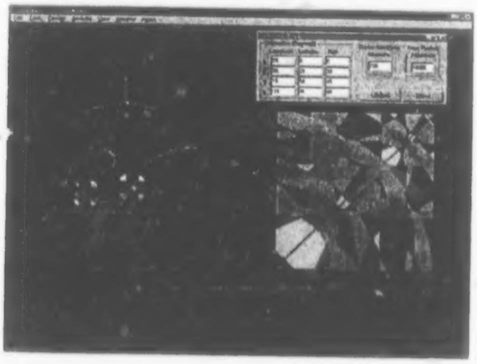

Figure 1. SphinxPC interface.

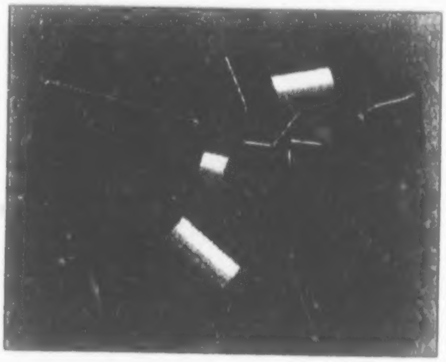

Figure 2. Solid model of mounting linkage.

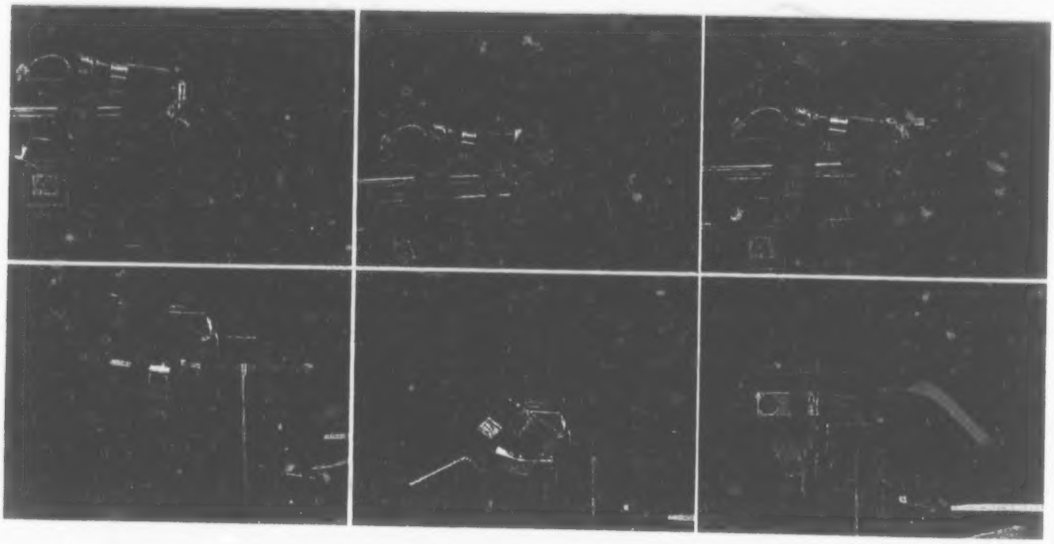

Figure 3. Movement of mounting system from the stowed to deployed positions: a-c. Side View; i-iii Front View.

DESIGN

The mounting system draws power from the 12 or 24 volt DC battery of the powered wheelchair. This drives DC gearmotor that can provide 300 in-lbs. of torque, yet weighs only 3 lbs.

A ***LaBac*** 10-1C variable speed interface is used to connect a Tash microlight switch to the power circuitry. The motor is powered in opposite directions with each activation of the Tash switch. Physical limits and microswitches identify the end of travel both in the stowed and deployed positions. Safety features include a current overload circuit which shuts the system off if an excessive torque is required, and a quick disconnect clamp which disengages the mounting linkage if needed.

The system is mounted to the wheelchair using standard ***DaeSSy*** wheelchair mounting components. These components connect to any 7/8" tube and are easily adjustable, so the system is adaptable to almost any wheelchair configuration. A schematic is shown in Figure 4.

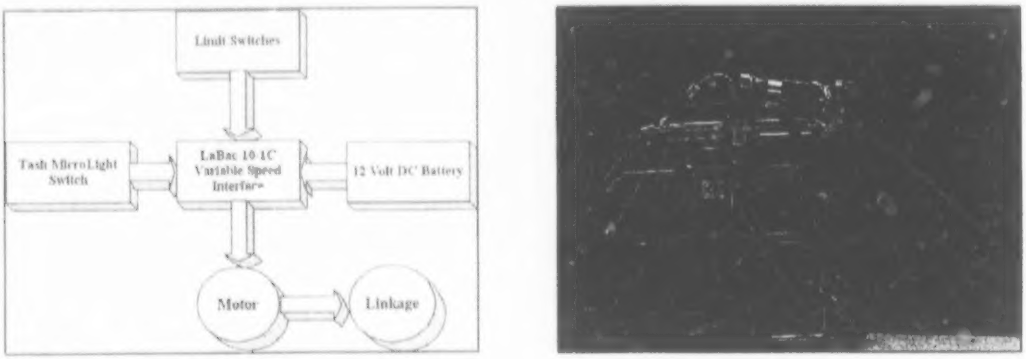

Figure 4. a. Schematics of the mounting system, b. Photo of the mounting system components.

DISCUSSION

The UCI Mounting System has been evaluated by CART and recommended for implementation for a volunteer client. It will be adapted for the Zygo LightWRITER^{TM} communication device. The client's experience with the device will be monitored by CART to provide insight to refinements for the design of the system. Of particular interest is the utility of this device and its impact on the independent activity of the user.

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Student Scientific Paper Competition

(Sponsored by Whitaker Foundation)

1999 Student Scientific Paper Competition Sponsored by Whitaker Foundation

On the following pages you will find the five award winning papers for the sixth annual RESNA Student Scientific Paper Competition. The student awardee is listed as the first author on each of the papers. These awards are supported through the generosity of the Whitaker Foundation. The purpose of the Student Scientific Paper Competition and Awards is to encourage and promote student participation in high quality research related to the fields of rehabilitation engineering and assistive technology. The competition is intended to encourage students from a variety of disciplines to address issues in the field of assistive technology and submit papers for presentation at the annual RESNA conference. This competition is based on scientific merit of the reported research and is structured to be distinct from, and complimentary to, the student design competition.

The winning papers were presented in a special session at the RESNA '99 Conference. This session provides a unique forum which, in addition to highlighting student research activity, brings together papers on diverse topics for presentation. Members of the Student Scientific Paper Competition Committee scored each paper after careful review based on the following criteria:

- General quality of the writing and presentation.
- Clear statement of hypothesis or research issues to be addressed.
- Choice and description of appropriate methodology.
- Presentation of the results.
- Discussion of the results and their significance.

I would like to sincerely thank the review committee for this year's competition: Glen Ashlock, Jon Gunderson, Heidi Koester, Jon Schuch, Mark Novak, Mary Baxter, and Mike Rosen. They faced very difficult decisions in choosing the five winners as most of the papers were deemed meritorious.

On behalf of RESNA, I wish to thank the Whitaker Foundation for its support, the judging committee for a difficult job well done, and all the students who submitted papers. I invite students to start planning their research for submission to the 2000 RESNA Student Scientific Paper Competition.

Richard Simpson, ATP
Chair, RESNA Student Scientific Paper Competition

RELATING WHEELCHAIR SETUP TO PROPULSION BIOMECHANICS

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ABSTRACT

The purpose of this study was to investigate a relationship between at-rest shoulder position with respect to the rear wheels and propulsion biomechanics in a group of experienced manual wheelchair users. The horizontal distance between the shoulder and rear wheel axle of forty experienced manual wheelchair users at rest and in their own wheelchairs was determined. Using kinematic and kinetic data collected during two and four mile per hour trials, pushrim contact angle, propulsion start angle, frequency, and peak rate of rise of the resultant force were compared to shoulder position relative to the rear axle.

At rest shoulder position was significantly correlated to start angle and stroke frequency at both speeds and with contact angle and resultant force rate of rise at four miles per hour. Applying this information in the prescription and setup of wheelchairs could lead to a reduction of biomechanics leading to median nerve dysfunction.

INTRODUCTION

To date, there has been very little scientific rationale behind the prescription and setup of manual wheelchairs. One area worthy of investigation is the prevention of repetitive strain injuries (RSIs) in manual wheelchair users (MWUs). In performing early studies on wheelchair prescription and performance, Brubaker felt that the factor of most practical significance for rim-propelled wheelchairs was user position relative to the drive wheels.(1) In addition, he felt that this position was a function the location of the shoulder joint axis relative to the rear wheel position. This study investigated several wheelchair propulsion parameters as a function of shoulder position with respect to the rear wheel axis. We hypothesized that a further forward shoulder with respect to the rear wheel while sitting at rest would result in: greater stroke frequency, lesser pushrim contact angle, greater peak and rate of rise of pushrim forces, and further forward beginning of the propulsion stroke.

METHODS

Subjects

Forty (28 male and 12 female) experienced MWUs with a spinal cord injury at T-3 or below volunteered for, and gave written consent to participate in this study.

Shoulder Position Determination

Subjects were secured to a dynamometer in their own wheelchairs with markers attached to the acromion process, the third metacarpophalangeal joint (MP), and to the rear axle of their wheelchair, as shown in Figure 1. With subjects sitting at rest and in their normal seated positions, the horizontal distance between the shoulder and hub markers was recorded using a motion analysis system (OPTOTRAK, Northern Digital Inc).

Biomechanical Parameter Determination

Bilateral kinetic data was collected during two and four mph trials from force and torque-sensing SMART^{Wheel}s mounted on the subject's wheelchair. After subjects reached steady state propulsion, kinetic data was collected for twenty seconds. SMART^{Wheel} data was used to determine the peak and rate of rise of the resultant force, the stroke frequency, and the contact angles. The position of the third MP marker and the rear wheel marker were used to determine the propulsion start angle.

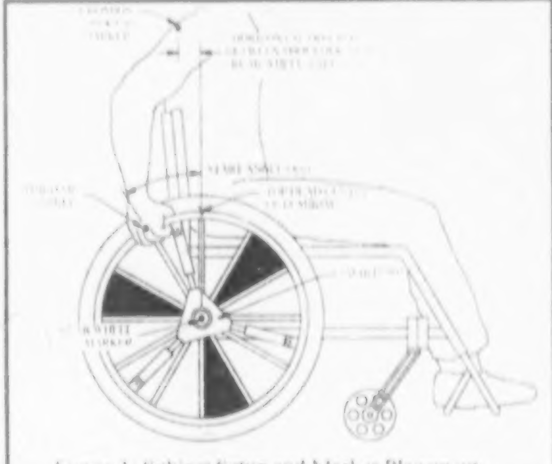

Figure 1: Subject Setup and Marker Placement

ANALYSIS

Propulsion Variables

All propulsion variables were averaged over the first five strokes except for frequency, which was calculated by the number of strokes in the twenty-second trial. Contact angle was determined by the rear wheel angle of rotation between the application and release of force on the pushrim. Peak and maximum rate of rise (ROR) of the resultant force were calculated as described previously.(2,3) Upon application of force, the position of the third MP with respect to pushrim top dead center (TDC) was used to determine the propulsion start angle.

Statistical

Using SPSS, Pearson partial correlations between the at-rest horizontal distance of the shoulder with respect to the rear wheel axle and each propulsion variable were determined. Correlations for each speed trial were calculated while controlling for height, age, years with a spinal cord injury (SCIYRS), and speed between all subjects. Pearson bivariate correlations were calculated for all propulsion variables between hands at both speeds.

RESULTS

The mean age and years post injury of this group of MWUs was 35.3 and 11.4 years respectively. The mean height was 69.4 inches. The correlations for propulsion variables between each side were high ($r > 0.8$) and therefore averaged between sides.

At a confidence level of $p < 0.05$, the shoulder position relative to the rear axle was positively correlated with the frequency and negatively correlated with the start angle. At four mph the frequency and resultant force maximum ROR were positively correlated while the contact angle and the start angle were negatively correlated, as shown in Table 1.

Propulsion Variables (N=40)	2 mph				4 mph			
	Frequency (Hz)	Contact Angle (deg)	Start Angle (deg)	Resultant Force Max ROR (N/s)	Frequency (Hz)	Contact Angle (deg)	Start Angle (deg)	Resultant Force Max ROR (N/s)
Corr. Coeff	0.381*	-0.324	-0.342*	0.156	0.445**	-0.431**	-0.353*	0.415*
2-Tailed Sig.	0.022	0.054	0.041	0.365	0.007	0.009	0.012	0.012

Table 1: Propulsion Variables and Horizontal Shoulder Position with respect to Wheelchair Rear Axle

(*) Indicates 2-tailed significance at $p < 0.05$; (**) Indicates 2-tailed significance at $p < 0.01$

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GENDER DIFFERENCES IN THE KINEMATIC FEATURES OF MANUAL WHEELCHAIR PROPULSION

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ABSTRACT

Eight female and seven male subjects participated in the recording of three-dimensional motion during manual wheelchair propulsion. Subjects were divided into two groups consisting of five gender based pairings for each group. Pairings were based on anthropometric percentiles for Group I and anthropometric similarity for Group II. Recorded data was analyzed to determine subject propulsion technique and joint range of motion at the shoulder and elbow. Whereas characterization of propulsion technique did not indicate notable differences based on gender of the user, statistical analysis of mean joint range of motion via a paired t-test found statistically significant ($p<0.05$) and strong statistically significant ($p<0.001$) differences. Further investigation into the force generation between genders is recommended to determine the basis for these differences.

BACKGROUND

Research into manual wheelchair propulsion (MWP) has documented resulting cumulative trauma and repetitive strain disorders in manual wheelchair users (MWU). (1) Researchers have asserted such injuries can be reduced by proper wheelchair fit and propulsion technique. Such assertions are based on the opinion that better wheelchair fit and efficient propulsion technique improves MWP physiological and biomechanical efficiency. (2)

In one such study, Shimada (3) characterized MWP stroke patterns and reported data on the joint accelerations and joint range of motion. Stroke patterns were characterized similar to Sanderson and Sommers (4) as semi-circular (SC), single looping-over propulsion (SLOP), and double looping-over-propulsion (DLOP). Mean maximum angular accelerations of the elbow and shoulder joints were calculated. Joint range of motion was reported using shoulder flexion/extension (sagittal plane), shoulder abduction/adduction (frontal plane), and elbow flexion/extension (sagittal plane projection).

Studies such as Shimada, however, have not considered the gender of the MWU. Reasons for considering the gender of the MWU include gender differences such as anthropometry (user-size) and strength. Occasionally, previous research into MWP has identified different subject groups which are characterized by gender, but no research appears to have been conducted solely concerned with the effect of gender on MWP.

Pheasant (5) notes the two most commonly cited gender differences are related to linear body dimensions and strength. These differences are often expressed as a female to male ratio (F/M) which considers an average member of each gender. Such comparisons provide very limited information since the ratio says nothing of the linear measure and strength distribution of each gender. Thus, simply considering a ratio ignores the overlap between each group. However, Pheasant notes care must be taken in making observations between subjects who are toward the tails of each respective distribution such that a stereotypical male academic is not compared with a female tri-athlete. Taken as a whole, the differences in limb length and strength may cause the MWU to produce differing MWP techniques based on gender. Thus, the purpose of this paper is to investigate the gender differences of MWP to determine whether additional research is required to properly fit the MWU dependent on their gender.

METHODS

Anthropometric measures of forty-five MWUs (13 females, 32 males) were recorded followed by motion analysis of the user's MWP technique. Anthropometric measures included weight, linear measures (stature, upper arm and forearm length) and circumference measures (axillary arm, elbow, wrist, and fist). Motion analysis was performed using two three-camera OptoTrack units. Markers were placed on the third and fifth MP, radial and ulnar styloid, olecronon, lateral epicondyle, acromion, and chest. The chest marker consisted of a three marker unit to quantify orientation. Propulsion was recorded for 20 seconds after a speed of 2 mph was maintained by the subject.

While exhaustive anthropometric surveys exist (5,6), one must be careful in applying this data to the population of MWUs. This is due to changes in an individual's body composition after spinal cord injury (SCI). For example, atrophy of the leg muscles cause a change in weight and increased use of one's arms may cause an increase in muscle thus affecting a change in circumference measures. For these reasons, only the linear measures of the existing anthropometric databases are applicable to the MWU population. Since this leaves only three measures for comparison of subjects in the study (stature, upper arm and forearm length), a simple matching of subjects with 50th-percentile data was not appropriate. An alternative was achieved by identifying subjects of each gender with comparable linear measures and then computing correlation coefficients using the subject circumference measures. It was postulated that circumference measures were indicative of the subject's musculature and, thus, subject pairings exhibiting high correlation relative to circumference measures have proportionally similar musculature. This method was used to identify five female to male subject pairings.

Female:Male Pairing	Linear Percentile (Stature/Uparm/Forearm)
1 (F5:M30)	F5(40/<1/1):M30(35/<1/2)
2 (F3:M6)	F3(20/1/30):M6(35/3/37.5)
3 (F1:M13)	F1(65/40/35):M13(35/42/75)
4 (F4:M9)	F4(97/90/60):M9(85/87/75)
5 (F7:M15)	F7(99/99/90):M15(97/92/82)

Table 1: Percentile Pairings

An effort was also undertaken to compare males and females of similar anthropometric measures. For this comparison, the male subjects' measures subtracted from the females'. Five pairings were made between males and females whose anthropometric differences for all measures summed to less than 10 cm and upper extremity correlation coefficients exceeded 0.95.

Female:Male Pairing	Upper Ext. Measure Difference (cm)	Upper Ext. Correlation Coefficients
6 (F3:M23)	10.2	0.973
7 (F4:M6)	6.0	0.971
8 (F9:M31)	7.9	0.977
9 (F12:M6)	6.0	0.961
10 (F13:M23)	7.2	0.952

Table 2: Anthropometrically Similar Pairings

A previously developed forward kinematic model (7) was adapted to calculate the inertial velocities and accelerations of each marker and derived joints. Joints were derived by averaging the position of the lateral epicondyle and olecronon for the elbow and the radial and ulnar styloids for the wrist. The shoulder and distal end of the hand were represented by the acromion and 3rd MP landmarks. Angle range of motion was found for the frontal and sagittal motion of the chest and upper arm. Sagittal and in-plane flexion/extension at the elbow was also determined.

RESULTS

Propulsion technique was categorized as defined by Shimada (4) as semi-circular (SC), single looping-over propulsion (SLOP), and double looping-over-propulsion (DLOP). Conceptually, the hand remains below the pushrim during the recovery phase in the SC pattern, whereas it rises above the pushrim in both the SLOP and DLOP patterns. SLOP and DLOP are differentiated in that the hand does not go below the pushrim for the SLOP technique, but does eventually drop below the pushrim for the DLOP technique. Propulsion technique for all pairings is summarized in Table 3.

Percentile Pairings

Pairing #	Propulsion Technique
1 (F5:M30)	SC : DLOP
2 (F3:M6)	SC : SC
3 (F1:M13)	SLOP : SLOP
4 (F4:M9)	DLOP : DLOP
5 (F7:M15)	SLOP : SC

Anthropometrically Similar Pairings

Pairing #	Propulsion Technique
6 (F3:M23)	SC : SC
7 (F4:M6)	DLOP : SC
8 (F9:M31)	SLOP : SLOP
9 (F12:M6)	SC : SC
10 (F13:M23)	SLOP : SC

Table 3: Propulsion Technique Comparison

Joint angles were evaluated to determine range of motion (ROM) for shoulder abduction/adduction (frontal plane), shoulder flexion/extension (sagittal plane), and elbow flexion/extension (sagittal plane). Subject pairings were compared statistically by identifying four sets each containing four propulsion cycles. Average ROM was found for each set which facilitated use of a paired t-test to compare each subject pairing. T-test results are summarized in Tables 4 & 5. (Note: In Tables 4 & 5. no statistical difference = "-", statistical difference = "+" ($p<0.05$), strong statistical difference = "++" ($p<0.001$).)

Percentile Pairings

Pairing #	Shoulder Ab/Adduction	Shoulder Flexion/Extension	Elbow Flexion/Extension
1 (F5:M30)	-	++	++
2 (F3:M6)	++	+	+
3 (F1:M13)	-	+	+
4 (F4:M9)	-	+	++
5 (F7:M15)	+	-	-

Table 4: Joint Angle Comparisons for Statistically Significant Differences (Percentile Pairings).

Anthropometrically Similar Pairings

Pairing #	Shoulder Ab/Adduction	Shoulder Flexion/Extension	Elbow Flexion/Extension
6 (F3:M23)	++	+	+
7 (F4:M6)	++	++	++
8 (F9:M31)	++	++	+
9 (F12:M6)	++	+	++
10 (F13:M23)	+	+	+

Table 5: Joint Angle Comparisons for Statistically Significant Differences (Anthropo. Similar Pairings).

DISCUSSION

Comparison of propulsion technique using the classification described by Shimada does not demonstrate notable differences based on gender of the MWU. This can be seen from the summary provided in Table 3 and by noting that when divided into gender based groups, 3 females & 3 males used SC, 4 females & 2 males used SLOP and 1 female & 2 males used DLOP.

Statistical analysis however, demonstrated statistically significant differences in the joint angles for the percentile pairings and a high degree of difference for the anthropometrically similar pairings. One possible reason for greater difference between pairings 6-10 versus 1-5 may be due to strength differences between females and males with similar linear anthropometrics. Further investigation into differences in the force generated between these pairings may shed light on the kinematic observation.

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COMPARISON OF SIDE-TO-SIDE WHEELCHAIR PROPULSION FORCES USING AN ARMA MODELING TECHNIQUE

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ABSTRACT

This paper addresses the use of a system identification approach known as the autoregressive moving average (ARMA) model to characterize wheelchair propulsion forces. The ARMA technique is used to find the coefficients of a mathematical equation describing a signal, system or process. In this application the ARMA technique was used to create a model force waveform based on current and past values of digital pushrim force data. The feasibility of the ARMA analysis is explored by using the model to compare side-to-side resultant force strokes of twenty wheelchair users.

INTRODUCTION

Excessive use of a manual wheelchair has been associated with the prevalence of pain and injury in the upper extremities (1,5). To investigate the causes of pain and injury in manual wheelchair users, researchers have developed sophisticated devices and techniques by which to characterize the kinetics and kinematics of wheelchair propulsion. Due to the complexity of data collection, researchers often perform unilateral data collection and analysis of biomechanical parameters. Unfortunately, there is little evidence that supports that manual wheelchair users propel in a symmetrical manner. Side-to-side asymmetrical propulsion can result in higher loads and stresses on one upper extremity thereby increasing the likelihood of injury to that side.

Investigating the bilateral kinetics of propulsion can be clinically useful in identifying precursors to upper extremity injury. The purpose of this research was to investigate side-to-side differences in wheelchair propulsion patterns using a method known as ARMA modeling (4). The ARMA model is unique in that it creates a new signal that is independent from the original waveform. This signal takes into account the entire shape of the stroke and therefore is a comprehensive method by which to compare side-to-side force waveforms.

METHODS

Subjects: Twenty experienced manual wheelchair users gave written informed consent to participate in this study. The sample consisted of 13 males and 7 females with a T4 level spinal cord injury or below. The mean age of the subjects was 33.3 ± 8.7 years and number of years post-injury was 10.6 ± 6.7.

Kinetic Data Collection: Subjects' own personal wheelchairs were fitted bilaterally with SMART$^{\text{Wheels}}$, force and torque sensing pushrims. Wheelchairs were secured to a dynamometer with a resistance comparable to that of a tile floor (3). After an acclimation period, the participants were instructed to propel at a constant speed of 0.9 m/s (2 mph) for 20 seconds during which three-dimensional force data were collected. The three-dimensional pushrim forces, Fx, Fy, Fz were computed directly from the SMART$^{\text{Wheels}}$. The resultant pushrim force is defined as:

$$F = \sqrt{(Fx^2 + Fy^2 + Fz^2)} \qquad (E\text{-}1)$$

Construction and Application of the ARMA model: The ARMA model describes the properties of a waveform based on its immediate past and present discrete values of the resultant force (F) and an error signal (e). The model force ($\hat{F}$) is determined by the following difference equation:

$$\hat{F}(k) = \sum_{i=1}^{M} a_i F(k-i) + \sum_{j=1}^{N} b_j e(k-j) + e(k), \qquad (E\text{-}2)$$

where k represents each sample instant and M and N represent delays in time for F(k) and e(k), respectfully. Expanding the right hand side of Equation E-2 results in the following expression:

$$\hat{F}(k) = -a_1F(k-1) - \ldots - a_MF(k-M) + e(k) + b_1e(k-1) + \ldots + b_Ne(k-N), \qquad (E\text{-}3)$$

The terms $a_1 \ldots a_M$ and $b_1 \ldots b_M$ are the ARMA model coefficients. These coefficients can be grouped together to form a single variable, θ. A simplified expression of Equation E-2 and E-3 is shown below (Equation E-4).

$$\hat{F}(k) = \theta^T u + e \qquad (E\text{-}4)$$

$$\text{where: } \theta^T = [a_1 \quad a_2 \ldots a_M, b_1 \quad b_2 \ldots b_N]$$

$$u^T = [F(k-1) \quad F(k-2) \ldots F(k-M), e(k-1) \quad e(k-2) \ldots e(k-N)]$$

The ARMA coefficients (θ) are determined from Equation E-4:

$$\theta = \mathbf{R}^{-1} \times \mathbf{P} \quad \text{where: } \mathbf{R} = [u\,u^T] \text{ and } \mathbf{P} = [u^T F] \qquad (E\text{-}5)$$

The order of the ARMA process is M and N and was determined through the use of singular value decomposition (4). The "best" order for the ARMA model was found to be M= 4 and N=0. An N=0 indicates that the error in the system approximates white noise and therefore, past values of the noise are uncorrelated.

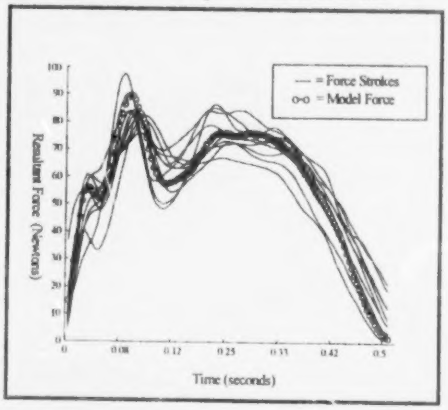

Figure 1: A single subject's resultant force model stroke (o-o) and all 11 left side resultant force strokes (—)

Each subject's first 11 right and left side resultant force strokes were used for this analysis. The sixth stroke from each side was combined to form a single stroke using the *spline* function in MATLAB (MathWorks, Inc.). The coefficients (θ) for the model were determined by applying Equation E-5 to the combined stroke. A model force stroke, $\hat{F}$, was created using equation E-2. This model stroke was compared to all other strokes, that is, the five strokes occurring prior to and after the sixth stroke of both the left and right sides (see Figure 1). Estimate error, E, was determined by subtracting each raw force curve, F, from the model curve, $\hat{F}$:

$$\hat{F}(k) - F(k) = E(k) \qquad (E\text{-}6)$$

The root mean squared (RMS) error value for all strokes except the 6th stroke was calculated using equation E-6. The RMS error values were then averaged across the ten strokes resulting in one RMS error value for the left side and one RMS error value for the right side. A paired t-test using a $p < 0.05$ was used to determine statistically significant differences between sides.

RESULTS

Right and left side RMS errors are shown in Table 1. Five of the twenty subjects demonstrated statistical differences in their side-to-side propulsion pattern. Of the five, RMS errors were greater for the right side in three cases and the left side for two cases.

DISCUSSION

In this application, a representative resultant force digital waveform (a combined right and left side stroke) was modeled using a 4th order difference equation and compared to individual raw resultant force waveforms that occurred prior to and after the modeled stroke. Variations between the model stroke and original strokes were used to determine side-to-side differences in propulsion forces. Previous methods used to characterize wheelchair propulsion kinetics have included analyzing the peak and/or average force values (2). Neither method accounts for the entire stroke pattern. Furthermore, side-to-side strokes are assumed to be correlated and dependent and thus researchers will often perform biomechanical analyses on only one side. The ARMA modeling technique is different in that it creates a new signal, an estimate error E(k), that is independent from side-to-side allowing for the use of a t-test for testing statistical significance. The results of this study show that statistically significant side-to-side differences were evident in 25% of the individuals who participated in this study. This finding makes it difficult for researchers who perform unilateral wheelchair propulsion analyses to generalize their results to the other side.

CONCLUSIONS

The ARMA modeling technique is a comprehensive method to investigating wheelchair propulsion forces. Future research will involve applying the ARMA model to other kinetic variables and also kinematic parameters for a more thorough analysis of wheelchair propulsion. In addition, the relationship between radiological and clinical evidence of upper extremity injury and side-to-side differences will be investigated.

Table 1: Right and left side RMS error analysis of model resultant force stroke and 10 original resultant force strokes

Subject	mean RMS errors Left (n=10)	mean RMS errors Right (n=10)
1	8.15 (1.5)	7.42 (2.5)
2	9.4 (2.0)	10.11 (2.6)
3	8.0 (1.9)	8.43 (2.0)
4	5.46 (2.0)	4.83 (1.7)
5	17.26 (11.8)	19.68 (9.2)
6	11.66 (3.6)	15.26 (4.3)
7	9.53 (2.9)	12.59 (4.7)*
8	6.48 (2.5)	7.71 (2.2)
9	12.74 (5.4)	15.1 (5.3)
10	8.53 (1.7)	8.76 (2.7)
11	13.92 (3.9)*	9.87 (3.4)
12	12.62 (4.1)	10.86 (4.6)
13	11.28 (3.4)	10.92 (3.6)
14	8.22 (2.3)	7.78 (2.9)
15	8.27 (2.3)	11.3 (2.9)*
16	12.19 (5.7)	13.29 (5.0)
17	14.65 (5.7)	11.49 (3.25)
18	8.98 (2.5)	14.16 (3.2)*
19	5.82 (2.4)*	4.3 (1.4)
20	11.68 (5.3)	11.28 (3.6)

Note: * denotes the side with significantly larger RMS error values ($p<0.05$)

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FEASIBILITY OF EEG CONTROL FOR A HAND GRASP NEUROPROSTHESIS

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ABSTRACT

Cortical control of a neuroprosthesis using the electroencephalographic (EEG) signal was investigated. Three subjects were trained to control the amplitude of the beta rhythm of the EEG recorded from the frontal areas. After six months, all subjects had achieved the ability to use this signal to hit targets placed randomly on a computer screen with a better than 90% accuracy rate. These subjects were also capable of generating limited arm movements while controlling the cursor. One subject with an implanted neuroprosthesis also demonstrated the ability to operate his neuroprosthesis with the EEG signal..

BACKGROUND

Functional neuromuscular stimulation (FNS) has restored functional hand grasp in individuals who have sustained a spinal cord injury at the C5/C6 level. The current hand grasp neuroprosthesis developed at Case Western Reserve University and the Cleveland VA Medical Center [1] electrically excites the muscles of the forearm and hand to provide the user with two possible grasp patterns. The control over hand opening and closing is provided by either an external or implanted transducer mounted at the shoulder or the wrist. However, as the neuroprosthesis develops to allow its implementation in both arms or in persons with higher cervical level injuries, the need for other methods of controlling the system becomes greater.

Several alternatives for control of a neuroprosthesis have been described. These include myoelectric control, head movement, respiration control, and voice control. Another method which has been proposed is the use of cortical signals recorded through the use of intracortical electrodes. However, the implementation of this is not anticipated in the near future. A more immediate method of using cortical signals to operate the neuroprosthesis would be to use the EEG. Other investigators [2,3] have demonstrated that subjects can be trained to control a specific frequency component of the EEG and use this to operate cursor movement on a computer screen. The simple signal provided by this method could be used to operate a neuroprosthesis if certain fundamental questions are first addressed.

RESEARCH QUESTION

The objective of this study was to address issues related to using the EEG to operate a neuroprosthesis and then implement an EEG-based controller. These issues were: 1) whether subjects could generate limited arm movements while controlling the EEG and, 2) whether electrical stimulation of the muscles would interfere with the recording of the EEG. The beta rhythm was investigated in this study since it is recorded from the frontal areas which are not directly responsible for extremity movement. Also, because this signal is not a multiple of the frequency of the electrical stimulation, little effect of the electrical stimulus on the recordings was anticipated.

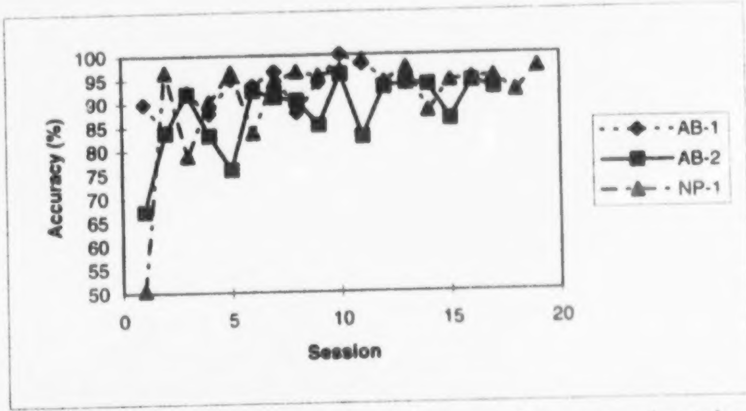
METHODS

A total of three subjects (two able bodied and one neuroprosthesis user) participated in this study. The instrumentation and protocols used to train subjects to control the amplitude of the beta rhythm were identical to those used by Wolpaw in his studies [2]. Each of the subjects were seated in front of a monitor, upon which appeared a cursor in the middle and a target at either the top or bottom. Subjects were trained to identify mental states or thoughts which would achieve cursor movement toward the target. The EEG signal was recorded from all areas of the brain using 64 electrodes arranged in a modified 10-20 format. For cursor control, only the beta rhythm (18-35 Hz) recorded from the frontal areas using five electrodes was used. Training for each subject involved one to three sessions per week. Each session consisted of 8 runs, 3 minutes in length, with anywhere from 30 to 35 targets per run.

Once a greater than a 90% accuracy rate was achieved, each subject participated in a subsequent experiment to evaluate the effect of voluntary limb movement upon cursor control. The subject was seated in front of a table upon which were placed the computer monitor, a 0.5 kg weight, and a divider. The subject was instructed for the first two runs to move the cursor as usual. In the next run, the subject was then instructed to move the cursor while moving the weight with their right hand over the divider. The next run involved the subject repeating the movement with their left hand. The series of non-movement, right movement, and left movement was then repeated twice, for a total of 10 runs. For the one neuroprosthesis user, this protocol was modified in that the subject was asked only to move his hand from his lap to the table and touch the weight. All other aspects were the same. To address the issue as to whether the electrical stimulation would interfere with the control of cursor movement, the neuroprosthesis user was asked to turn his system on, and then proceeded with a normal training session. The system was turned off between runs to prevent fatigue of the muscles due to continuous stimulation.

The neuroprosthesis user participated in one final study where the instrumentation used to generate cursor movement was interfaced with the neuroprosthesis. The movement of the cursor up generated a command to open the hand, while down movement closed the hand. The subject was given 30 minutes to adapt to the new controller, and was then asked to use this new controller to manipulate a fork, a cup, and a weight.

RESULTS



The ability of the subjects to control the amplitude of the beta rhythm, as measured in the accuracy rate, is shown in Figure 1. The subjects have participated in anywhere from 10 to 20 training sessions during a six month period. All three subjects were able to achieve excellent control, achieving accuracy rates well above 90%. From the graph, it is also seen that control is learned in approximately 6 sessions and that once it is learned, it is maintained.

Table 1 shows the effect of movement upon the subjects ability to control the beta rhythm as measured in accuracy rate. From this data, it can be concluded that movement has little effect upon the control of the beta rhythm. The poor results seen with the neuroprosthesis user with right side movement are related to the fact that the recording cables were becoming entangled with an orthosis on that hand. The effects of neuroprosthetic operation upon beta rhythm control were also limited.

The subjects overall accuracy rate was 93.5%, which is only 1.5 % lower than the subjects average accuracy rate.

Subject	Non-movement	Right	Left
AB-1	100 %	100%	100%
AB-2	91.5%	94.8%	96.1%
NP-1	97.9%	86.4%	96.1%

The one neuroprosthesis user was able to effectively manipulate all three objects using the EEG-based controller with his current neuroprosthesis. However, the new controller only allowed the subject to open and close the hand and not lock it in any one position. To maintain his grip upon an object, the subject had to maintain a low amplitude signal (down cursor movement) continuously, which became harder to do as the subject became tired.

DISCUSSION

The analysis of the data indicates that the use of the beta rhythm is ideal for operation of the neuroprosthesis. Subjects have effectively demonstrated that they can achieve a high degree of accuracy with the signal, and can maintain this level of accuracy while generating voluntary movements or while the neuroprosthesis is in operation. The answers to these questions were critical in determining if the EEG signal was feasible as a control source for the neuroprosthesis. The results for the final study demonstrate that the EEG signal is a feasible option for controlling the neuroprosthesis. Further work is underway to develop algorithms to covert the EEG signal into neuroprosthetic control which would allow subjects to maintain their hold upon an object for a long period of time, as well as to provide finer control over the amount of hand opening and closing (i.e. to achieve positions between fully open and fully closed).

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CLINICAL USE OF IN SITU PRESSURE SENSORS FOR PROSTHETIC SOCKET FIT? SCIENTIFIC CHARACTERIZATION OF THREE SENSOR SYSTEMS

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ABSTRACT

The eventual goal of this research is to identify biomechanical measures that aid prosthetists with socket fabrications, thereby decreasing the likelihood of soft tissue trauma. Bench testing was performed to assess accuracy, hysteresis, drift, and response to curvature for three different pressure measurement systems. Results indicated low accuracy errors for the Novel prototype sensor and Tekscan F-Socket, but large errors were recorded for the Rincoe SFS sensor. Hysteresis and drift errors were large for the F-Socket sensor, but low for the other two types. Older sensors and curved surfaces tend to increase the amount of error, whereas sensor calibration prior to testing reduced error in the system measurements.

BACKGROUND

Socket fabrication is a highly refined art that relies on the skill and experience of the prosthetist. If pressures are insufficiently distributed, amputees may develop problems including pain, discomfort, pressure sores, and associated infections. Subsequently, these conditions could preclude prosthetic use until the soft tissue has fully recovered. Currently, the most utilized method of inspection for pressure distribution relies on visual and verbal feedback during clinical visits to the prosthetist office. Recently, several publications have indicated the need for the quantification of residual limb socket interface stresses (5). It has been recommended that a thorough characterization of commercial systems and their transducers. The Rincoe SFS, Tekscan F-Socket, and the Novel prototype socket sensor are three such systems designed for in-situ measurement of interface pressure. Clinical techniques for quantification of biomechanical measurements with these systems are not common in prosthetic practice. This is perhaps due to cost, difficulty in clinical interpretation of the data, and time required for operation. Furthermore, there are no published reports on the validity of these prosthetic pressure sensor systems save a few reports (1). The clinical validity of sensor systems with similar technology has been shown in other fields such as podiatry (2,3,4).

RESEARCH QUESTION

The objective of this research is to initiate the first steps toward establishing a clinical system of biomechanical interface pressure measurements in the field of prosthetics. The measures should enable the clinician to assess both static and dynamic fit more accurately and determine appropriate socket modifications more scientifically. This study assesses the potential feasibility of three current pressure measurement systems in the clinical environment through a variety of bench tests.

METHODS

Preliminary testing was conducted using a flatbed chamber to assess the sensors under ideal circumstances (Figure 1). The chamber had an adjustable control module and ranged in pressure

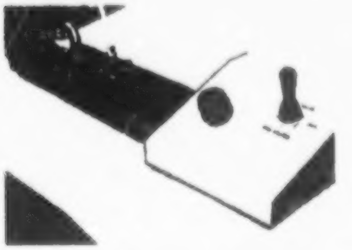

Figure 1 Flatbed Chamber (far left) with Pressure Regulator

Figure 2 Custom-Modified Pressure Vessel

from 0-690 k- 3 -Pa (0-100 psi). To assess the effect of placing sensors over curved surfaces, a customized pressure vessel was fabricated (Figure 2). Sensors were placed on nine sites of a positive transtibial residual limb mold, and an ICEROSS® silicone liner (Össur USA, Carpenteria, CA) was rolled over the mold to secure the sensors. The mold together with the attached sensors and silicone cover were placed into the pressure vessel and the vessel was sealed.

Accuracy testing was performed in different pressure increments for both systems. Measurements for the Rincoe SFS system were taken in 15 kPa (2 psi) increments ranging from 0-83 kPa (12 psi) for both flatbed and mold testing. For the F-Socket system, measurements were performed in 69 kPa (10 psi) increments ranging from 0- 550 kPa (80 psi) for the flatbed and 0-345 kPa (50 psi) for the mold testing. For the Novel prototype socket sensor system, measurements were performed in 50 kPa (7 psi) increments from 0-550 kPa (80 psi) for the flatbed and 0-345 kPa (50 psi) for the mold testing. Hysteresis measurements were taken in similar increments for all systems as in accuracy for both increasing and decreasing pressure points. The highest error for each trial was represented. Drift tests were performed in 5 minute intervals at different pressure points for a total time frame of 20 minutes. For the Rincoe SFS system, recordings were performed at 34.5 kPa (5 psi) and 69 kPa (10 psi) for mold and flatbed testing. The recordings for the F-Socket system were taken at 138 kPa (20 psi) and 410 kPa (60 psi) for the flatbed tests and 69 kPa (10 psi) and 275 kPa (40 psi) for the respective mold testing. For the Novel prototype socket sensor system, the recordings were performed at 138 kPa (20 psi) and 410 kPa (60 psi) for the flatbed tests and 69 kPa (10psi) and 275 kPa (40 psi) for the respective mold testing.

RESULTS

The results of the bench testing for all systems are demonstrated below (Table1).

Test	Rincoe		Tekscan		Novel	
	Flat	Mold	Flat	Mold	Flat	Mold
ACCURACY	24.7% (n=360)	32.9% (n=200)	32.9% (n=200)	10.7% (n=200)	2.4% (n=120)	9.99% (n=2240)
HYSTERESIS	15.1% (n=270)	23.1% (n=200)	41.88% (n=192)	23.4% (n=128)	6.95% (n=1200)	7.02% (n=960)
DRIFT	6.23% (n=288)	10.1% (n=12.8)	14.2% (n=384)	27.8% (n=128)	4.41% (n=960)	6.39% (n=1280)

Table 1. Overall Summary of Results. n = sample size. % = %error

DISCUSSION

The Rincoe SFS system pioneered the clinical use of interface pressure assessment at the residual-limb socket interface by using force sensitive resistive dye. This was followed by similar sensor technology used by Tekscan, namely the F-Socket Measurement System. Most recently Novel has added their contribution to this area which utilizes capacitance based sensors, Novel prototype socket sensor system. In all three testing areas the Novel system did better than the other two systems. However, even though the F-Socket system had better accuracy results than the Rincoe system, the hysteresis and drift results were better for the Rincoe system. This may due to the use of different substrate material or resistive dye. The Rincoe SFS sensor substrate material is rather brittle, while the F-Socket sensor substrate is slightly more malleable. This is especially critical for placing the sensor strips over highly contoured sites. The ability to contour to the mold allowed for better accuracy for the F-Socket system. Similarly, the Novel substrate is silicon based which allowed for the best contouring to curved surfaces of all three systems tested, thereby surviving the clinical testing period with minimal physical damage.

Preliminary studies indicate favorable results for the Novel prototype socket sensor system, as compared to the Rincoe Socket Fitting and F-Socket systems. It is the belief of the authors that the Rincoe and F-Socket systems should be used cautiously and only to obtain relative and comparative pressure values. The Novel prototype socket sensor system, however, seems to offer the most potential for accurate and quantitative clinical use. Future studies involving humidity and temperature are also necessary for all three systems in order to get an even more complete view of their potential.

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